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THE CONTRIBUTION OF ROENTGENOLOGY TO MEDICINE AND SURGERY IN THE LAST TWENTY-FIVE YEARS

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ON THE coat of arms of the State of Michigan appears an inscription, "If you would behold a beautiful peninsula, look about you." To appreciate the contributions of roentgenology to medicine and surgery in the last quarter of a century, it is only necessary to look about one, for the state of roentgenological progress which we see in the practice of medicine today represents the progress of roentgenology since 1906. One needs only to review the status of roentgenology twenty-five years ago to realize the benefits conferred on medical and surgical progress in that time.

There are really two viewpoints from which a survey of the last quarter-century's progress in roentgenology might be measured: (*a*) the degree of progress as measured by the published papers in the various branches of medicine and surgery prior to 1906; (*b*) the progress as measured by the degree to which the medical profession as a whole and the textbook writers prior to 1906 had assimilated the teachings of those devoting themselves to roentgenology.

If we judge by the first standard, we shall admit that almost everything in our present refinements of roentgenological practice had been conceived and to some degree elaborated before 1906; and those present-day practices which are generally considered as late contributions to diagnostic and therapeutic roentgenology were many of them foreseen and the possibility of their later realization voiced in the first decade of our employment of the discovery of Professor Roentgen. If, however, we judge by the degree to which roentgenology had entered into medical practice, we shall appreciate that the roentgen rays in internal medicine had not reached anything like general recognition by the end of the tenth year following Roentgen's first publication.

As a criterion of the degree to which the roentgenologic method had been accepted in medical diagnosis and treatment twenty-five years ago, one might properly consult a 1905 edition of Osler's "Practice of Medicine." In the index to this work there is no reference to any word relating to the x-rays or to Roentgen. A rather careful survey of the text shows very scanty mention of the roentgen ray or its application in medicine. In diagnosis the x-rays are mentioned only twice, once under urinary stone and once under aneurysm of the aorta; four other references relate to the therapeutic use of the rays. The reference is usually very brief; that relating to aneurysm is the longest, consuming nine lines. In other words, under six headings, remarks are made about the x-rays to the extent of 223 words in a mas-

sive volume of approximately 600,000 words.

One recognizes immediately the attitude of the skilled physician, adept in physical diagnostic procedures, loath to resort to acceptance of any kind of mechanical aid to the time-honored employment of sight, touch, and hearing, the accurate use of which requires a high grade of training and experience. Teachers of diagnostics often bemoan the fact that students are always seeking to have their problems solved by the roentgen ray instead of trying to develop their skill in palpation, percussion, inspection and auscultation; they feel that the roentgen-ray help is tending to replace rather than to confirm and amplify the older methods.

From the standpoint of the surgeon, it may be interesting to contrast the original prognostications as to the future value of roentgen rays with the actual recognition accorded them by surgeons in 1906, and with the present widespread dependence upon roentgenological help.

One of the earliest references to the x-ray appeared in the issue of the *Journal of the American Medical Association* of March 7, 1896, page 491, as follows:

> Roentgen Photograph.—The surgeons of Vienna and Berlin believe that the Roentgen photograph is destined to render inestimable services to surgery and medicine. Case after case is reported where unsuspected formations were revealed by the photograph, indicating slight operations which restored patients to health and cured deformities. Half an hour is the shortest exposure possible, and most require an hour. The electric apparatus required is so expensive, $100 and upward, that few surgeons can use it yet in their private practice.

If the writer of the above paragraph could see the elaborate and highly efficient roentgen institutes of the present time he would realize that at least one branch of roentgenology has made notable progress.

Some in 1896 even doubted that the roentgen rays would ever materially assist so generally in medicine and surgery as at first sight was supposed. M. Gariel, Professor of Physics in the Paris Medical Faculty, asked how it was possible that this method could be applied to the greater number of organs contained in the human body. In the thorax, for instance, the organs placed behind the sternum and those in front of the vertebral column would not be made clear. He thought the same difficulty applied to photography of the stomach, liver, kidney and heart. M. Gariel said it would be rash to declare that these organs would never be successfully studied, but he considered it barely probable. However, the later literature of roentgenology reveals a change of belief and a continued interest on the part of Professor Gariel and his important participation in many of the researches leading to the application of the roentgen rays to internal medicine and surgery.

Many of the early claims were ludicrous as they appeared in the public newspapers. It was reported, for instance, that at Columbia University the shadow of a bone was projected on the brain of a dog and he immediately became hungry. Otto Glasser reports the instance of a New Jersey lawmaker who introduced into his legislature a law prohibiting the use of x-rays in opera glasses. It is easy to understand the overenthusiasm of newspaper reporters when interviewing workers with the new rays.

In March, 1896, Dr. W. W. Keen was reported as recognizing that the applications of the new rays to surgery were valuable, but he thought in a limited range.

However, from its discovery until the end of the first decade of its life, the new science made rapid strides in its application to surgery, as shown by the thousands of articles appearing in the medical press, for the most part in that section of the medical press relating to the roentgen ray.

Let us examine a standard surgical textbook (fifth edition of Da Costa's "Modern Surgery") published in January, 1907. In the text there is no mention of the x-rays in the diagnosis of aneurysm, acromegaly, leontiasis ossium, osteomalacia, osteomyelitis, osteitis deformans, skull fractures,

pleural effusion or empyema, esophageal obstruction and diverticula, carcinoma or ulcer of the stomach, or gallstones, and not even in gastroptosis or splanchnoptosis. The text contains brief mention of the x-rays under the headings of stone in the kidney, ureter and bladder; tuberculosis of bones, joints and perhaps certain forms of pulmonary tuberculosis; abscess of the lung; all types of fractures, "though the evidence is not always satisfactory;" dislocations of various types; foreign bodies in the esophagus and stomach; bronchial foreign bodies. Brief mention is made of the possibilities of benefit from x-ray therapy in sarcoma, carcinoma, lymphadenoma, certain tuberculous lesions, and in certain diseases of the skin. A brief note is also given, "it is claimed by some that the x-rays retard bacterial growth."

As a sort of reparation for the above lack of appreciation of the x-rays, in an appendix to this work the author devotes ten pages to a somewhat more modern conception of the application of x-rays to surgery. Attention is called to the value of the x-rays in locating foreign bodies consisting of opaque material, and, after abdominal operation, in locating a Murphy button and determining when it has loosened and descended. It was thought that urinary stones should be detected although we are cautioned that the kidney is very deeply placed, under the ribs and close to the vertebral column, so that some kidney stones might escape detection. Reference was made to the finding of a drainage tube lost in the pleural sac, and of a few isolated cases of the finding of gallstones (Cattell, Carl Beck and Thurstan Holland). Several pages are devoted to the detection and localization of foreign bodies, reference being made to triangulation, skiagraphy over a surface marked in squares, the insertion of guide needles, and the use of Sweet's apparatus, which later became so useful in relation to foreign bodies in the eye. Fractures and dislocations come in for a more generous discussion than in the text of the work, and reference is made to the diagnosis of the position of the fetus in utero. "Applied to the soft parts, the new process has obtained interesting but not as yet many practically useful results . . . . The shadow of the heart can be made out, and the outlines of the diaphragm, kidney and liver can be thrown upon the screen. If the stomach is distended with gas, it shows as a light area upon a dark background. If food is eaten after being mixed with subnitrate of bismuth, the outline of the viscus becomes fairly distinct. Thickened pleura, pleural effusion, pulmonary consolidation, abscess of the lung, pericardial effusion, aortic aneurism, cavities in the lungs, and atheromatous blood-vessels may be made out with more or less distinctness."

It is hard for us to understand such lack of grasp of the possibilities of roentgenological aid to surgery and medicine, because we know that before the above was written (and it seems to represent the 1906 standard of acceptance of roentgen methods into practical medicine and surgery) Cannon and Williams had published their famous pioneer work on the use of opaque materials in the alimentary tract; Rieder, Pfahler, Holzknecht, Schwarz, Leven and Barret, and numerous others had reported their work on opaque meal studies of the digestive tube; and Williams, Crane, Holzknecht, Béclère, Holland, Kraft, Rieder, and Hulst, among others, had placed before the medical profession papers on roentgenology of the thorax which left little to be added in the twenty-five years which have since passed. Roentgenologists of the United States are particularly proud of Crane's early paper on the diagnosis of diseases of the thorax. The contributions of Francis Williams were especially valuable; his textbook is perhaps the most important publication in English during the first decade of roentgenology. The volume by Pusey and Caldwell (1903) is another outstanding early publication of historical value.

However, the work of the various men mentioned in the preceding paragraph represented far-advanced points of pioneer

effort to promote practical roentgenology into general medical and surgical practice, as witness the above excerpts and references from two standard textbooks of 1906 by Osler and by Da Costa. The average physician used the roentgen rays very little and appreciated scarcely at all their value in any but fractures, dislocations and foreign bodies. Even physicians specializing in roentgen practice were spending their major energy in developing the technical aspects of their work. Exposures were still much too long. The pioneer work of Cannon and Williams in introducing the bismuth meal was unrecognized for years, because the long exposures spoiled the roentgenograms of the moving organs. It was only after short exposures became possible that organs in peristaltic activity could be recorded on the plate, and just then came Rieder's work. So Rieder usually is accorded the credit for the opaque meal. To attempt to show a fractured rib, it was necessary to strap the chest. Jacob, in 1906, in examining for renal calculus mentions a point it might be well for some of us to utilize at times. Because of the long exposures, it was necessary for the patient to breathe during the application of the rays. So he instructed his patients to breathe violently for as long as they could, and then to rest, with the result that they breathed very quietly for several minutes.

A review of the roentgenological literature for 1906 shows much of the effort of the year expended on problems relating to apparatus, and shorter exposure, and measurement of radiation. An international committee was appointed to seek a universal standard of x-ray measurement. Much interest was exhibited in discussions of radiotherapeutic problems, especially the treatment of cancer.

Among the diagnostic problems of the tenth year concerning which papers were published in English may be mentioned the following:

Kingscote successfully demonstrated a dilated heart, and Guilleminot talked on orthodiagraphy.

The now world-famous orthopedist, Sir Robert Jones, with David Morgan wrote an exhaustive treatise on osseous formations in muscles due to injury (traumatic myositis ossificans).

Thurstan Holland published a beautiful roentgenogram of a gallstone in a living patient, verified by operation, and Jacob wrote several papers on renal calculi.

Carl Beck (New York) had previously recorded several cases of gallstones.

A. Stanley Green, and G. E. Pfahler wrote on a more extended use of the roentgen rays as an aid in the diagnosis of pulmonary tuberculosis. Pfahler discussed consolidations, cavities, emphysema, pulmonary abscess, gangrene, pneumonia, pulmonary collapse, pleural effusion, pneumothorax, and subphrenic abscess.

Holzknecht wrote on the roentgen diagnosis of carcinoma of the stomach. Rieder at this same time talked of the roentgen examination of internal organs, with special reference to the use of bismuth subnitrate. He also used bismuth subnitrate for demonstrating the large intestine.

Voelcker and Lichtenberg described the process of studying the pelvis of the kidney by the introduction of a 5 per cent solution of colloidal silver through a catheter.

Newcomet and Talley stressed the value of the fluoroscope in studying chest diseases, mentioning particularly deep-seated pneumonia and malignant metastases.

Frederick Baetjer wrote a classical paper on thoracic aneurysms.

Coley, Stover and Pfahler discussed at length the treatment of sarcoma and carcinoma, the latter, with Johnson, recommending ante- and post-operative treatment of carcinoma of the breast.

Joseph A. Capps, Pancoast and others read important papers on leukemia and other diseases of blood-making organs.

Charles Lester Leonard, in whose honor the American Roentgen Ray Society has established a prize, in his presidential address on the "Past, Present and Future of the Roentgen Ray," mentioned in surgery its value in fractures, in better understand-

ing of many problems in pathology, especially in orthopedic surgery, and increased efficiency of treatment. The problems of calculous nephritis and ureteritis were an example, for besides increasing the accuracy of diagnosis this method had cleared up the pathology and altered the indications for operation. Leonard went on to say: "In medical diagnosis, the thorax, on account of its sharp contrasts in densities, has accorded the most fertile field. Fluoroscopic examinations have rendered valuable results, but the greater accuracy has followed the advent of instantaneous exposures. The employment of opaque solutions in the hollow viscera is not a method of recent date, but the rapid exposure has increased their value and great progress may be expected in this direction."

A perusal of the titles on the first decade of roentgen literature listed by Hermann Gocht astounds one because of the numerous contributions. There are no less than 125 roentgenological books and atlases dated 1905 or earlier. One easily sees that the early literature contains the suggestion, at least, if not a more practical contribution, toward most of the refinements of the roentgen diagnostics of internal medicine and surgery which we are prone to consider of quite recent origin. In the field of technical development, for instance, there are very few innovations of today which were not illustrated or mentioned in some way in the work of Rollins. The textbook by Pusey and Caldwell contains much of sterling worth today, besides constituting a historical document of no small value.

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To enumerate the contributions of the last twenty-five years means simply to subtract from our present attainments in roentgenological practice the sum of the advancement recorded during the first ten years. It would require a large book to detail the elaborations of technique and of apparatus, and of the application of the improved technique to the newer problems of medicine and surgery. The advances in the field of pathology, in which the roentgen rays have helped materially, have, on the other hand, widened the field of application of the rays.

From 1906 we have gone on to the development of the serial examination of the alimentary tract; the differentiation of gastric from duodenal ulcers; the elaboration of gall-bladder diagnosis through indirect signs seen in the gastrointestinal examination; the differentiation of various benign tumors, and even the differential diagnosis of various types of malignant tumors; the recognition of diverticula and their complications; and most recently there has been much development in the study of the mucosa of the digestive tract, which bids fair to still further revolutionize and improve our diagnostic accuracy in digestive disorders. It is only natural to recall in this connection that the original communication of Friedenwald on gastric ulcer was based upon observation of a retention of opaque material in a defect in the gastric mucosa, a point which has been forgotten during the intervening years, now to be recalled again. The classical work of Haudek, and of Barclay, Cole, George, and Carman, all served to put gastroduodenal diagnosis on a firm footing. The contributions of Holzknecht, Haenisch, and others too numerous to mention, further strengthened our diagnostic armamentarium, particularly in relation to the colon. Schwarz developed much in relation to the physiology of the colon.

Postoperative uses of the roentgen ray include studies of the function of organs which have been altered by surgical procedure; the discovery of gastrojejunal ulcers and adhesions; the confirmation of postoperative ileus; subphrenic abscess; the position of faulty drains and fistulae; the progress of pulmonary postoperative complications. Occasionally postoperative studies of the function of a gastrojejunostomy teaches one how to correct an apparently faulty function by educating the patient to assume certain postures after eating, to favor emptying of the stomach.

In the chest important developments

have occurred in cardiac studies, especially by Groedel, Schwarz, Dietlin, Holmes, Steel and numerous others. The contributions of Manges on foreign bodies in the bronchi; of Pancoast on pneumoconiosis; of Stewart, Forestier and others, on bronchiectasis and the diagnosis of pulmonary and bronchial tumors; of Sante, and others, on massive collapse of the lung and pneumonia; of a whole host of roentgenologists, including Dunham, Crane, Cole, the group from the Saranac institution, and others on pulmonary tuberculosis—these all constitute only a small estimate of the development of roentgenology of the thorax.

It would be an endless task to continue naming the men and the steps for which they have been responsible in leading us to our present high stand in roentgenological practice. I have said very little relating to the urinary tract. The introduction of opaque media into the ureters was a development of 1905, but it has been greatly elaborated. The addition of iodized oils to the roentgenologic methods opened up widely new channels for exploration of disease of all the bodily cavities—of the nasal sinuses, the bronchi, the urinary tract and the female genital organs. The perfection of Graham's method of cholecystography has immensely advanced diagnosis of biliary tract disease. Out of Graham's success grew the stimulation necessary to bring success to the experimenters with opaque media for use in intravenous urography and arteriography. An entire new chapter has been added to the roentgenology of the abdomen, pelvis and cerebrospinal nervous system through the perfection of methods of introducing air or gas into various body cavities.

Enough to say that if one of my readers does not appreciate the tremendous strides made by our science since the founding of this Journal, he should follow my example in beginning with the January, 1896, issues of some of the more important medical journals and reading the articles relating to the very beginnings of the x-ray and the first ten years of its development, to realize how grand a structure has arisen in the last quarter of a century from the first communication of Roentgen on December 27, 1895.

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PROGRESS IN THE DEVELOPMENT OF ROENTGEN-RAY APPARATUS

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THE past twenty-five years have added much to medical knowledge in general and to roentgenology in particular. Most of the latter is due to the same causes which have produced the former, but the development of roentgen appliances is not a small factor in this advance. In paging over the transactions of the American Roentgen Ray Society of 1906 and 1907 and comparing them with those of the present day one is impressed by the fact that the same subjects were discussed then as now, the only difference being that those of the later day indicate the general advance in medical knowledge as well as that gained by twenty-five years of additional roentgen experience. In paging through the advertising columns one finds an entirely different story, as the appliances which were indicated at that time have now been entirely superseded and replaced by other machines and accessories. The static machine was still commonly used especially by those who used it as a therapeutic instrument. However, the static machine was largely displaced by the coil which was largely a development from those found in physics laboratories and had reached a comparatively high stage of efficiency. Some of the workers preferred a coil giving a long thin spark up to 36 inches, while others preferred a coil giving a short heavier spark up to 12 inches. Many of the coils had a device for varying the primary winding. Thus one winding was used for diagnostic work and another for therapy. The Kinraide coil, Grosse Flamme, and the Golden Spark will doubtless recall many fond memories. Some of the earlier coils had the faculty of burning out at the most inopportune moments, but this was overcome in the later models. The interrupters were of various kinds of which the mechanical was the one earliest in use. Its capacity was very limited, it was exceedingly noisy, and the contact points required frequent replacing. The mercury interrupters were of two types, the jet and the plunger. They were of greater capacity than the mechanical and were far less troublesome, but they heated quickly and the "mud" which was formed by the breaking down of the mercury into dust and its mixing with the oil required very frequent cleaning of the instrument. However, they were safe and the jet type is still used by many for fluoroscopy and some types of therapy. The interrupter most commonly in use for diagnostic work was the electrolytic, of which the Wehnelt was the popular type. It could be used for either the alternating or direct current and a large amount of current could be used in the primary. In order to increase this amount multiple anodes were used by some. They were by far the most satisfactory type of interrupter in use for plate making but due to over-heating were seldom used for prolonged fluoroscopy or treatment. To overcome this heating tendency, however, several interrupters were placed so that it was a simple matter to change from one to the other. The pots containing the electrolyte were usually placed in large water baths to facilitate cooling. When in action they were quite noisy and gave off highly objectionable acid fumes so that it was desirable to have them placed in an adjoining closet or room. The current delivered by a coil was distinctly jerky in character and left much to be desired in its effect upon the tube, so that the development of some other type of high tension generator seemed desirable. The current delivered by a static machine was eminently satisfactory in that the current was unidirectional and the effect on the tube good. However, the amount was negligible, so that the length of the exposure needed was greater than with the coil. Dr. Henry Hulst of Grand Rapids, Mich., was so impressed by the desirability of this

current that he made a machine with 36 revolving plates. It, too, was found unsatisfactory.

Mr. Lemp of the General Electric Company on December 1, 1897, applied for a patent on a motor driven mechanical rectifier in a high tension circuit of an alternating current transformer. This patent was allowed November 1, 1904. In January, 1904, Franz J. Koch was given an English patent for a high tension mechanical rectifying system. This was described in 1903, in *Annalen der Physik*, Vol. 14, and by a further article in *Fortschritte auf dem Gebiete der Röntgenstrahlen* in 1904–05 by F. J. Koch and K. A. Sterzel, which shows a high tension transformer with a tapped primary adjustment, primary resistance, etc.; in fact, as complete a machine as the one with which the roentgen public is familiar. In July, 1907, Snook applied for a United States patent on a somewhat similar device, the chief difference being in the amount of the wave which was rectified. His patent was issued in April, 1910.

It should be stated that Snook in 1903, while a graduate student at the University of Pennsylvania, undertook a series of studies to attempt to improve the discharge from a spark coil. He made an oscillographic study of the spark and was impressed by the amount of inverse discharge as well as by the long interval between the inverse and the direct discharge of the coil. The problem which then presented itself was how to keep the inverse out of the tube. This led to the development of a synchronous series spark gap by means of which the inverse was completely suppressed. Further oscillographic study, however, showed that a large amount of energy in the inverse was wasted. This led to the building of a synchronous reversing high tension switch which put both the direct and inverse discharges through the tube. This discharge came from a coil with a mercury interrupter. The results were improved but the oscillographic study still showed a large waste of time between the waves and a very poor wave form. He then decided to build a closed magnetic transformer to be excited by the alternating current which led to the interrupterless type of apparatus. It should be stated that he was in entire ignorance of the work of Lemp and the other early workers. The first Snook machine was placed in operation in the Jefferson Hospital in the service of Dr. Manges in June, 1907, and was shown at the Cincinnati Meeting of the American Roentgen Ray Society in October, 1907.

Caldwell had an idea that the ideal current for doing all types of roentgenologic work was the static or one similar to it. With this in mind, he constructed a nine phase high tension alternating current generator, the current of which he attempted to rectify by means of a series of valve tubes, the later types of which were equipped with an automatic regulator. A description of this valve tube is found in Volume V of the *American Journal of Roentgenology*, page 567. These experiments were begun in 1906 and a machine was in actual operation four years later. The results obtained were not as satisfactory as had been hoped for due to the instability of the valve. Further experimentation was impossible due to his sickness and untimely death.

Dushman in the *General Electric Review* of 1915 describes a new device for rectifying high tension alternating currents. This is a kenotron which was constructed upon the now well-known fact that certain heated metals permit the passage of an alternating current in one direction only. He states that this effect had been described by Edison, and that Fleming applied it as an electric valve to rectify electric oscillations, etc. In speaking of the applications of the kenotron he said that the combination of kenotron and transformer could be used to displace the cumbersome static machines and still more complicated mechanical rectifiers that are at present used to produce high voltage direct currents for roentgen tubes, etc. Certainly his opinion has been borne out and proved by the gradual development of the valve tube machines the world over. The first American made valve

tube machine was manufactured by the Wappler Electric Company in 1924.

Occasionally it was desirable to make examinations at the bedside of patients who could not be moved. The ordinary induction coil as used in the office was not readily portable and of course the static machine was out of the question. A smaller coil was therefore developed. Various types of these were in the market of which the high frequency type was the one most commonly in use. However, Caldwell constructed a coil of a 6 inch spark gap with a vibrating interrupter which was very satisfactory. Occasionally, examinations were requested where either the alternating current or none at all was available. Storage batteries were then called into use.

During the War it was evident that the type of portable apparatus just described was not satisfactory so that Shearer devised the so-called bedside unit. This was a closed core type of transformer and operated the radiator type of Coolidge tube. The first of these instruments was made by Waite and Bartlett.

The development of the gas tube from the simple one which Roentgen used up to the time when Coolidge gave us the hot cathode tube is perhaps the most interesting of all the earlier developments. The change of the point of impact of the cathode stream from the glass wall to a metal target, the change of the focus spot from a wide one to a smaller one; and the use of various metal targets (platinum, irridium, nickel, silver, and tungsten) tell a very interesting story. It seems that the earliest roentgen tubes in this country were made by a glass-blower named Greiner for Eimer and Amend but very shortly after this Robert Machlett of New York started making tubes, to be followed very shortly by Greene and Bauer of Hartford, Conn., who were the first ones to make these tubes in any quantity. They were manufacturers of incandescent lamps at the time that Roentgen made his announcement. Other manufacturers of this period are Friedlander, Baker, and MacAllister and Wiggin.

Gas tubes were pumped to a certain vacuum and when operated became either higher or lower in vacuum. If the vacuum became high it was due to the fact that the residual gas was absorbed by the heating metals and the glass so that eventually no current or very little would pass through the tube. This difficulty was recognized very early and various kinds of regulators were applied. One of the first employed was that which had been used by Crookes in his early experiments and consisted in providing the tube with an auxiliary chamber containing potassium or sodium hydrate. By applying heat to this a certain amount of the water of crystallization of the salt was driven off and lowered the vacuum. This method was applied by Elihu Thompson to regulate the vacuum of roentgen tubes. In 1896 Mr. Sayen patented a tube with an automatic regulator which is familiar to all of us as the Queen self-regulating tube. This was improved upon by Mueller of Hamburg. The osmosis regulator was also extensively used, its functioning depending upon the fact that certain metals such as palladium become porous to hydrogen when heated to red heat. A tube of metal was sealed into the roentgen tube and when necessary was heated by a spirit lamp which allowed a certain amount of hydrogen to pass through the porous metal. If the tubes were operated too long they became "soft" and it was a very difficult task indeed to again harden them. The method of choice consisted in placing them on the shelf for a few days or weeks and trusting to luck. Sometimes these lowered tubes could be brought back to life by passing a very small amount of current inversely through them. Kelly in the *American Journal of Roentgenology*, Volume II, page 552, described the Snook hydrogen tubes which permitted both of lowering and raising the vacuum by taking advantage of the vigorous osmosis of hydrogen through certain heated metals, particularly palladium. This tube was pumped as high as possible and all of the residual gas in the metal and glass was removed. Hydrogen only was admitted

through the lowering chamber, and if it became too low some of it could be removed through another osmosis palladium regulator. Mutscheller in the *American Journal of Roentgenology*, Volume VII, page 261, describes the nitrogen tube. This tube was also pumped as high as possible and nitrogen only was admitted through an auxiliary chamber. If too much was introduced it returned to a standard pressure in about fifteen minutes.

Various devices were used for cooling these gas tubes. Hirsch in 1918 patented an appliance for submerging it in oil. Others subjected the tube to a blast of air. The water-cooled tube was in common use, especially for therapy. This consisted in having water circulating around the anode. The reservoir was usually attached directly to the tube, but some very ingenious devices were used by which rubber tubes connected the roentgen tube with a larger reservoir which was suspended close to the tube.

The current given off by the coil was not a unidirectional current and it was soon recognized that an appliance of some sort was necessary to smooth it out. Multiple spark gaps were first suggested and later on the valve tube was introduced. However, they left much to be desired as the vacuum in these tubes was not very stable.

In the fall of 1913, Dr. Lewis Gregory Cole invited a large number of roentgenologists to the Hotel St. Dennis in New York to hear a paper by Dr. W. D. Coolidge in which he described a new type of roentgen tube. The tube described is the hot cathode "Coolidge." A full description of this may be found in the December, 1913, *Physical Review* and a shorter description in Volume I of the *American Journal of Roentgenology*. Thus was introduced to the medical profession the most important apparatus since Roentgen's discovery, and it has now come into general use. The tube described is what is now called the Standard Tube. In the *General Electric Review*, January, 1918, and in the *American Journal of Roentgenology*, Volume V, Coolidge and Moore describe the special self-rectifying roentgen-ray tube which is now commonly known as the radiator type. And in the *American Journal of Roentgenology*, Volume IX, Coolidge and Kearsley describe the high voltage roentgen tube for deep therapy. These various tubes on account of their easy, accurate, and consistent operation have come into general use and have almost completely displaced all other types of tube. It seemed desirable for some types of work and to avoid the possibility of shock from high tension terminals to have an apparatus in which the transformer and tube were one unit. Accordingly Waite in 1919 constructed such a unit in which the tube and transformer were so constructed as to form one unit, both being immersed in the same oil bath. The first of these was sent to Dr. Hickey at Detroit and the second was sent to Dr. Coolidge. These instruments have since become very popular as the well-known dental and shock-proof units.

The development of fluorescent screens was brought about by the use of platinobarium cyanide in the physics laboratories for various purposes, but especially for the detection of the fluorescence of the cathode stream. Roentgen, for instance, used this material at the time of his discovery for that particular purpose, and so mentions it in his contribution.

The first American made screens were by Mr. Jackson of East Orange, N. J., and proved to be most satisfactory. The Hanovia Chemical Company of Newark also produced screens of this type.

While very satisfactory, these platinum screens deteriorated very rapidly so that some other more stable type of fluorescent material was sought. The Germans had for years used artificial willemite. This screen was marketed under the name of Astral Fluorescent Screen.

The discovery of the fluorescence of calcium tungstate was made by Mr. Arnold (dissertation, Erlangen, *Ann. Phys.*, 1897, *61*, 314) and its use as a fluorescent screen was suggested by Mr. Thomas Edison (*Elect. Eng.*, 1897, *21*, 305). The use of this

material for fluorescent screens has now come into general use.

Early in the roentgen era it became evident that some sort of a device was necessary by which the time factor of plate exposures could be materially reduced.

It was learned that by placing the emulsion-coated side of a photographic plate against a smooth, highly polished, reflecting surface such as nickel or silver the time factor could be reduced about one half. A further considerable reduction in the time of exposure may be effected by placing in contact with the plate a screen of material which fluoresces strongly with an actinic color.

Calcium tungstate was found to give a bluish-white color which was highly actinic. The first screens of this type were imported from Germany and were known as the Gehler Folie. These screens were not very satisfactory as the binder was dissolved by water when the screens were washed or even touched by a wet finger. However, the screens which were produced about 1908 were very satisfactory. At the 1912 meeting of the American Roentgen Ray Society at Niagara Falls Dr. Threlkeld Edwards introduced the first American-made screen. The Snook Lagless Intensifying Screen was introduced in 1913. The Patterson Screen came along about 1916. And in 1919 they brought out the double screens to meet the double-coated films of the Eastman Company. The cleanable screen appeared in 1921.

With the discovery of the x-rays, they were eagerly seized upon by physicians both for diagnostic and therapeutic purposes. Due to this it was necessary to devise means for supporting the tube and the patient during the procedure. The earlier tube stands were necessarily very crude, being merely of a supporting structure. The first stand of any pretense was marketed by the Kelley-Koett Company and bears a striking resemblance to that still in use. The tables then used were an adaptation of those used in general practice. However, various manufacturers soon appeared with special tables designed to facilitate x-ray work. Perhaps the best known of these were Scheidel-Western, Kelley-Koett, and the Snook. Upon returning from a European trip in the fall of 1912, Caldwell was very much impressed by the necessity for fluoroscopy and the advantages of a tilting table. He accordingly set to work to develop such a table and it was actually placed in operation that winter (*Am. J. Roentgenol.*, 1918, vol. 5).

On account of some unfortunate experiences in the early days of roentgenology, Americans were very loath to practice fluoroscopy. However, an application for a patent was filed July 5, 1906, and allowed August 1, 1910, by Harry F. Waite of New York City for a vertical fluoroscope device which provided for a movable protected box containing the tube and a movable lead glass-covered fluoroscopic screen, each of which might be moved independent of the other. However, the fluoroscope did not come into general use until about 1912.

Deep therapy was developed in Germany. American manufacturers were slow in accepting the idea, so that the first machines of this kind which were used here were imported. However, in 1921, the General Electric Company made a special machine and tube for the use of Dr. Case at the Battle Creek Sanitarium. Deep therapy outfits were placed on the market by the General Electric Company in 1922. These machines were an enlargement of the Snook type in general use. Other manufacturers followed readily in the production of these machines.

The early days of roentgen therapy were beset with various vicissitudes. The same tubes and exciting apparatus were used as for diagnostic work. It was recognized early that the rays were principally absorbed by the superficial tissues so that in the treatment of lesions in cavities such as the mouth, vagina, and rectum, tubes were made with long stems so that rays could be directed immediately to the lesion. One of these (which he made for treatment of lesions in the larynx), is mentioned by Cald-

well in the book published by Pusey and himself in 1904. For the determination of penetration of the tube the spark gap was preferred to the various appliances used abroad as the Wehnelt and Bauer penetrometers and the pastilles devised by Holzknecht and others were particularly used to determine the question of dosage. However, there were two Americans who early devised means of measurement. Crane of Kalamazoo devised the skiameter which consisted of graduated layers of tinfoil. This instrument was used for measuring shadows in the lung but was essentially a penetrometer, and was perhaps the earliest American instrument for determining penetration. Dr. Samuel Stern of New York devised and published the photographic method of determining dosage. This consisted of exposing strips of film to roentgen rays and developing them in a standard developer for a predetermined time. The dosage was established by comparing the film with a standard. Of the later developments, perhaps the constant-reading ionization chamber of Weatherwax is the most important contribution.

From all of this it is quite evident that the roentgenologist who walks into his modernly equipped office is confronted with quite a different series of problems from those which confronted his predecessors.

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THE RELATION OF THE AMERICAN JOURNAL OF ROENTGENOLOGY AND RADIUM THERAPY TO THE DEVELOPMENT OF RADIOLOGY

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THE American Journal of Roentgenology and Radium Therapy is a monument to its founder, Preston M. Hickey. It was founded by him in 1906 as the *American Quarterly of Roentgenology*. In 1913 it became the *American Journal of Roentgenology* and since that time has been issued monthly. Dr. Hickey was not only the founder but was the editor of the Quarterly and later of the Journal from its foundation in 1906 until the beginning of 1916, a decade momentous in the development of medical radiology. From its foundation to the present time this publication has been the official organ of the American Roentgen Ray Society and for the past decade of the American Radium Society. The American Roentgen Ray Society is not only the oldest radiological society in the United States but one has only to read over the early issues of its official organ to realize the important influence exerted by it on the progress of radiology in those early years. A small number of men, not over fifty, joined together in the American Roentgen Ray Society, rescued radiology from the hands of the charlatan and the non-medical mechanician and firmly laid the foundation of its final recognition as a specialty in medicine.

The list of members of the American Roentgen Ray Society during the early years of this century whose articles are published in the *American Quarterly of Roentgenology* reads like a roll of honor. Along with the name of Hickey whose recent death has caused his achievements to be reviewed, are the names of those pioneers who sacrificed their lives in the development of this new art. Mihran K. Kassabian of Philadelphia was a charter member of the American Roentgen Ray Society which was organized in 1900. He was a strong factor in keeping the influence of the Society on the side of legitimate and ethical medical practice. His death occurred in 1910 as a result of injuries received from fluoroscopy before the year 1900. His textbook "Electrotherapeutics and the Roentgen Rays" was published in 1907 and a second edition was brought out in 1910 about the time of his death. One of his early papers giving a summary of methods of measuring dosage in roentgen therapy was published in Volume I of the *American Quarterly of Roentgenology*.

Charles Lester Leonard of Philadelphia was internationally known for his work in roentgen diagnosis and therapy. He was among the first in the world to demonstrate the value of the roentgen method in the diagnosis of renal calculi. He was president of the American Roentgen Ray Society in 1904–1905 and delegate from the American Medical Association and the American Roentgen Ray Society to both the Fourth and the Fifth International Congresses of Radiology and Medical Electricity, the former held in Amsterdam in 1909 and the latter in Barcelona in 1910. Leonard and Prof. Holzknecht were appointed to report to the International Congress of Medicine which met in London in August, 1913, on the present status of the roentgen diagnosis of gastrointestinal lesions. Leonard was unable to attend the Congress and died after successive operations for roentgen injuries on September 22, 1913. His report, however, was published in the first number of the *American Journal of Roentgenology* which succeeded the Quarterly in November, 1913. That number is a memorial number to Charles Lester Leonard and in addition to his own posthumous article there is published a biography and appreciation by his fellow-townsman George E. Pfahler,

and a long list of Leonard's contributions to medical literature, practically all of them dealing with the uses of the roentgen ray in diagnosis and therapy.

Eugene W. Caldwell of New York was a contemporary of Kassabian and Leonard and like them died a martyr's death. The American Roentgen Ray Society perpetuates his memory and recalls his achievements in the Caldwell Lecture which is delivered by some outstanding man each year at the annual meeting. The lecture was delivered in 1928 by Preston M. Hickey. This lecture is published in full in the issue of the Journal for February, 1931, which was a memorial number to Hickey. In that lecture Dr. Hickey, who was a close personal friend of Eugene Caldwell gives an excellent summary of the latter's life and in considerable detail records his achievements in the field of roentgenology. Caldwell was an electrical and mechanical genius and numbered among his inventions the Caldwell electrolytic interrupter, roentgen tube for application of the rays to body cavities, and a stereofluoroscope. In the early days of this century he was joint author with Wm. Allen Pusey of a textbook entitled "The Practical Applications of the Roentgen Ray in Therapeutics and Diagnosis." For a number of years this was the standard textbook and reference work in this country. Perhaps his most important work in medical roentgenology was that on the nasal accessory sinuses. It was presented to the American Roentgen Ray Society in 1906 and published in the Quarterly in Volume I issued in that year.

Walter J. Dodd, of Boston, is another whose name appears frequently in the early numbers of the *American Quarterly of Roentgenology*. He was one of the guiding members of the American Roentgen Ray Society in its formative years and like Kassabian, Leonard and Caldwell, one who lost his life as the result of roentgen injuries. His influence as a teacher of roentgenology will long be felt in America. His pupil, George W. Holmes, who succeeded Dodd at the Massachusetts General Hospital has given training and inspiration to a large number of American roentgenologists who today are themselves teachers in medical colleges scattered over the entire United States. The pages of the *American Journal of Roentgenology* reflect the influence of Walter James Dodd through the innumerable contributions of his pupils, and of a newer generation whom his pupils have trained.

One is impressed in reading over the early numbers of the Quarterly and the Journal not only with the work of the outstanding men already mentioned who received fatal injuries in pursuit of their work but with the scientific contributions of many others who are well known to us and who still occupy honored places in the ranks of roentgenologists. It is impossible to mention all of them but the early issues of the Quarterly have preserved for us original work in many lines which is the very foundation of roentgenology today. I have already mentioned the work of Caldwell on the nasal accessory sinuses. Of scarcely less importance was that of Sidney Lange of Cincinnati on the diagnosis of mastoid disease. Other work on the mastoids had preceded his but he established the correct angle for making the roentgenograms and popularized the method. His technique is described in Volume II of the Quarterly published in 1909.

The name of William M. Sweet also occurs in the early issues of the Quarterly. He began his work on the localization of foreign bodies in the eye in 1898 and published a number of articles on the subject in that and succeeding years. In 1909 the *American Quarterly of Roentgenology* published an article by him entitled "Improved apparatus for localizing foreign bodies in the eyeball by the roentgen rays."

The Quarterly in a previous issue had published a paper by another of the early active members of the American Roentgen Ray Society, Charles F. Bowen, describing a simplification of Dr. Sweet's localizer. This was much used because of its simplicity and light weight by the U. S. Army Medical Corps during the world war.

Another name that recurs often in the early numbers of the Quarterly is that of H. Clyde Snook. His outstanding contribution to roentgenology and one of first rate importance was the invention of the so-called "interrupterless machine," but his influence in the development of roentgenology can be traced through other articles published in the early issues of the Quarterly.

There can, in fact, be found in the *American Quarterly of Roentgenology* from 1906 to 1913 an almost continuous story of the development of the art of roentgenology. In the diagnostic field Leonard showed the value of the roentgen ray in diagnosis of renal calculi, Caldwell in diseases of the nasal accessory sinuses, Lange in diseases of the mastoid, A. W. Crane, James T. Case and Lewis Gregory Cole in diseases of the gastrointestinal tract, and Francis H. Williams, A. W. Crane, and H. Kennon Dunham in diseases of the chest.

Roentgen therapy developed more slowly than roentgen diagnosis because of the unreliability of tubes in those early days. The articles in the Quarterly and the recorded discussions in the American Roentgen Ray Society give a picture of the difficulties and the many problems of the therapist. There one can gain a conception of the road followed in finally arriving at a knowledge of the effects of filtration and of the slow and gradual accumulation of experience which laid the foundation for proper conceptions of dosage. Many of the pioneers were interested in roentgen therapy, including those already mentioned in this article, but the outstanding work in America in those years was done by George E. Pfahler of Philadelphia. It was his work especially which showed the effect and value of filtration, and his courage, foresight and persistence which laid a solid foundation for the use of roentgen therapy in malignant disease. There were of course many others who contributed largely to the development of roentgen therapy whose articles may be read in the early issues of the Quarterly. Emil Beck wrote on the treatment of exophthalmic goiter, H. K. Pancoast on treatment of leukemia, Sidney Lange on treatment of enlarged thymus, Russell H. Boggs on treatment of carcinoma of the breast, and A. L. Gray on treatment of non-malignant growths in the larynx.

The *American Quarterly of Roentgenology* served not only for the publication of work of American roentgenologists but in its pages will be found original articles and many abstracts of articles by the roentgenologists of Europe. The names that stand out in those years are those of Guido Holzknecht, Alban Köhler and Fedor Haenisch.

The year 1913 was a very appropriate one for the enlargement of the Quarterly and the change from a quarterly to a monthly journal of roentgenology. It was in that year that great impetus was given to roentgenology by the invention of the Coolidge tube. William D. Coolidge made the first public demonstration of the Coolidge tube to a few roentgenologists in New York City on December 27, 1913. His first published description of his hot-cathode tube was in the *Physical Review* of December, 1913, a lengthly abstract of which was published in the third monthly issue of the *American Journal of Roentgenology* in January, 1914. Many articles by Coolidge will be found in issues of the Journal subsequent to that time, among them a description of the radiator tube and his latest contribution in the December, 1930, issue on "The development of modern roentgen-ray generating apparatus, the Caldwell Lecture of 1930.

In October, 1916, James T. Case succeeded Dr. Hickey as editor of the *American Journal of Roentgenology* and continued as editor until July 1, 1918. Soon after the entry of the United States into the world war Dr. Case went to France and had charge of x-ray work with the American Army. For some time he continued as editor with the able assistance of A. W. Crane who was associate editor, but in June, 1918, being still in France in active service he felt himself forced to resign. H. M. Imboden of New York then became editor and

as such directed the destinies of the Journal for the next five and a half years, until January, 1924.

During the war years the Journal reflects the activities of American roentgenologists in performing their part in carrying on the medical work of the army and navy. The work of the American Roentgen Ray Society under the presidency of Lewis Gregory Cole to assist in preparation for the roentgenological work of the war and the formation of schools for training military roentgenologists is described. There are articles describing bedside and portable apparatus and numerous descriptions of methods of localizing foreign bodies. Although roentgenology in general along with other branches of medicine more or less marked time during the war, there came out of war experience a great improvement in certain types of x-ray apparatus such as the radiator tube, the oil-immersed units and the bedside and other portable apparatus.

Soon after the close of the war the Journal in 1920 records a description by Hollis E. Potter of the Potter-Bucky diaphragm. This, with the development of x-ray apparatus of high power and the production of tubes with capacity of 100 milliamperes and up has greatly increased the precision and accuracy of roentgenographic work. All of these great advances and also articles dealing with the innumerable and seemingly unimportant scientific details upon which such advances depend will be found recorded in articles and abstracts in the pages of the Journal for the past ten years. Under the editorship of A. C. Christie from 1924 to 1929 and since that time of Lawrence Reynolds the Journal has been gradually enlarged to cover the ever enlarging field of radiology. In order that its title might better show its scope the name of the Journal was changed in 1923 to *The American Journal of Roentgenology and Radium Therapy*.

Radiology has now become a great specialty of medicine and occupies a large field both in diagnosis and therapy. The ideal of *The American Journal of Roentgenology and Radium Therapy* is to record in original articles and abstracts every advance that takes place in its field and to make accessible to every roentgenologist all new knowledge gained. It aims to be progressive but always along sound lines. As the President of the Rockefeller Foundation has recently said of medicine in general, "it seeks to be open minded toward new truth provided this can be rationally related to the great body of firmly established and organized knowledge." In roentgenology, as in every branch of human affairs, true progress must always be founded upon a knowledge of the past and must maintain a proper relationship between present activities and that great body of systematized knowledge laid up for us, often at great cost, by those who have gone before. A careful reading of the pages of *The American Journal of Roentgenology and Radium Therapy* for the past twenty-five years will give to every roentgenologist not only a knowledge of the history of his art but it will give him a better perspective for his work and a firm foundation for future progress.

This short and inadequate review of *The American Journal of Roentgenology and Radium Therapy* during the twenty-five years of its existence can be concluded in no better way than to call attention to a very important attitude of the Journal which is manifest in almost every issue from the first number of the Quarterly in 1906 to the latest issue of the Journal in 1931. That is, it has always been a journal of clinical medicine. It has given due space and consideration to the physical and biological sciences but it has been dominated constantly by the conviction that the problems of roentgenology are ultimately medical problems. It is the conviction of the writer that this is a sound position and one that should not be departed from in the future conduct of the Journal. The contributions of physics, chemistry and biology are essential for progress in the field of roentgenology but they must be evaluated and applied to medicine by men with medical

training. In conclusion, I quote from a recent address of James Ewing in support of this position. He speaks of Dr. James Douglas as follows: "He was distrustful of the tendency of the overmanned ranks of the fundamental sciences to reach out into medicine and appropriate medical problems for their own uses. He did not believe it was wise to make medicine a branch of biological science. He preferred to enlarge the ranks of medicine and encourage medically trained men to employ the fundamental sciences for the solution of the problems of the sick. He believed that medicine is essentially, and must always remain, a humanistic profession."

THE CONTRIBUTIONS OF A QUARTER CENTURY OF ELECTRON PHYSICS TO ROENTGEN-RAY SCIENCE

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WITHOUT electrons x-radiation could never be produced. Scientific inquiry has demonstrated clearly in these last few years that the physical universe consists of three things: (1) the positive electric charge (proton); (2) the negative electric charge (electron), and (3) the radiation due to sudden movements and rearrangements among these charged particles. In the words of Sir Oliver Lodge, "It is by the third or apparently supplementary, subsidiary, or accidental consequence of spasmodic behavior of the other two that we know anything about these and about the other worlds in space which they constitute." There is no more remarkable or brilliant page in all of science than that which depicts the growth in the experimental and theoretical science of electrons during the past quarter of a century. It is entirely appropriate, therefore, to sketch briefly some of these developments, particularly as they have a bearing upon the production of x-radiation and the effects as it traverses and is absorbed by matter.

A brief tabulation of some important dates and names in the history of investigation on the nature of electricity and electric discharges in gases and in vacuum will serve as a background for modern advances.

Very early Greeks: Amber rubbed caused attraction and repelling of objects.

1600 Gilbert: Glass rod, etc., electrified (amberized) by rubbing.

1650 Otto von Guericke: Invention of vacuum pump and static electric machine.

1705 Hawksbee: Observation of glow discharges (friction) in vacuum.

1733 Dufay: Sealing wax electrified opposite in property from rubbed glass, hence "vitreous" and "resinous" electricity.

1750 Benjamin Franklin: Defines positive and negative electricity (former if repelled by glass rod rubbed with silk; latter if repelled by sealing wax rubbed with cat's fur); one-fluid theory of electricity.

1753 Abbe Nollet: Discharges in evacuated globes connected with electrical machines.

1759 Symmer: 2-fluid theory of electricity.

1785 William Morgan: Production of Coolidge vacuum through which electric discharges did not pass; fluorescence as air is admitted (probably produced x-rays).

1822 Sir Humphrey Davey: Further studies of electric discharges in vacuo.

1833 Faraday: Faraday laws—valancy in chemistry exactly proportional to quantity of electricity; + and − charges appear simultaneously and in equal amounts.

1837 Faraday: Faraday dark space in evacuated bulb glowing with electrical discharge.
Experiments leading to induction coil and electric machinery.

1869 Hittorf: First observation of cathode rays.

1871 Crookes: Crookes dark space in gas discharge; independent discovery and study of cathode rays.

1874 Weber: Two types of electrical constituents of matter, one more mobile than other.

1879 Stoney: Atomic theory of electricity and first estimate of elementary electric charge.

1883 Wiedemann: Cathode rays as another form of ordinary light.

1883 J. J. Thomson: Conduction of electricity through gases by ionization.

1891 Stoney: Suggestion of word electron for natural unit of electricity.

1894 Lenard: Bringing cathode rays out of tube through thin window into outer air; deflection by magnet, etc.

1895 Perrin: Proof of negative charge associated with cathode stream.

1895 Roentgen: Discovery of x-rays in experiments on discharge of electricity through a well-exhausted vacuum tube.

1896 Becquerel: Discovery of radioactivity—one radiation (β) corresponding to cathode rays.

1897 J. J. Thomson: Measurement of velocity of electrons and of ratio of charge to mass $-e/m = 1.8 \times 10^7$ e.m.u.; cathode rays a flight of corpuscles very much smaller than lightest atom.

1897 Weichert: Independent measurement of e/m.

1897 Kaufmann: e/m from magnetic deflection; mass 1/1850 hydrogen atom.

1897 Townsend: Measurement of e from cloud formed from bubbling oxygen from electrolysis through water; 3×10^{-10} e.s.u.

1897 Lorenz: Zeeman effect measured obtaining value of e/m for oscillating electron in close agreement with e/m from cathode stream; hence identical; mass 8.9×10^{-28} grams.

1898 J. J. Thomson: Measurement of charges on a gaseous ion by Wilson cloud expansion method; 6.5×10^{-10} e.s.u.

1903 J. J. Thomson: Value 3.4×10^{-10} e.s.u.

1903 H. A. Wilson: Further improvements in droplet method 3.1×10^{-10} e.s.u.

1909–13 Millikan: Accurate measurement by balanced oil droplet of $e = 4.774 \times 10^{-10}$ e.s.u.

It is evident that about a quarter of a century ago the existence of corpuscular electrons as the units of negative electricity was established by the classic researches tabulated above, with a unit charge of 4.774×10^{-10} electrostatic units. Cathode rays or streams of rapidly moving electrons were found to be identical regardless of the gas in the discharge tube or the material of the cathode. This was but one of the evidences that electrons are a fundamental constituent of all matter and of atoms. Rapidly it was discovered that they are spontaneously emitted by radioactive disintegrations of heavy atoms and are called β rays. They are liberated as photoelectrons under proper conditions when radiant energy, visible light, ultraviolet rays, roentgen rays, etc., impinges upon matter. Glowing hot wires produce thermionic emission of electrons; heated gases associate into electrons and residual ions; free electrons course through metallic conductors as a flow of electric current.

Within the bounds of a short review it is impossible to present adequately even the briefest outline of all the investigations in the field of electronic physics during the past twenty-five years. Such a review would necessarily include all the progress in radio, photoelectric cells, properties of conductors and insulators, spectroscopy of every kind and innumerable other subjects. Consequently only a few subjects of especial importance to roentgen rays are selected, as follows:

(1) The development of a highly successful hot cathode roentgen-ray tube and cathode-ray tubes.

(2) The Bohr electron theory of atomic structure to explain the facts of roentgen-ray spectroscopy.

(3) Beta-ray spectra.

(4) The Compton effect and "Compton electrons."

(5) Electron impacts in gases.

(6) Electron diffraction and the dual nature of electrons.

(7) Displacement of the Bohr theory by modern quantum or wave mechanics and new ideas of the electron and atom.

(8) Physical, chemical and biological effects of roentgen rays as dependent on emission of photoelectrons.

ELECTRON TUBES

The Coolidge Tube.—In the electron-type tube it is necessary to have an independent source of electrons, since there is insufficient gas present to enable passage of the current. For a roentgen tube to operate with a pure electron discharge it is necessary to evacuate to the highest attainable vacuum, usually 0.01 bar or 0.0075 microns of mercury. These electrons may be supplied by application of the Edison effect, i.e., emission from a hot-wire cathode, or by oxides heated on the cathode, by illumination of the cathode by ultraviolet light, or by Lilienfeld's auto-electron-emission method. The first of these is the basis of the very familiar Coolidge tube which is now being manufactured on a large scale for deep therapy, diagnosis, diffraction analysis and superficial therapy. The original

Coolidge tube consisted of a glass bulb into which were sealed a solid metal target and a spiral of tungsten wire backed by a focusing shield of molybdenum as cathode. The emitting wire was 0.216 mm. in diameter, 33.4 mm. long and wound in a flat spiral of $5\frac{1}{2}$ turns with a diameter of 3.5 mm. The spiral was heated to incandescence by a current of 3–5 amperes at 1.8–4.6 volts supplied in an independent circuit from storage batteries or step-down transformers. Under these conditions the wire had a temperature of 1890 to 2540° Abs. Electrons were liberated and upon application of voltage to the terminals of the roentgen tube they were drawn across to the target. The ordinary commercial Coolidge tubes are usually supplied with tungsten or molybdenum targets. In the "universal" type the target is not cooled and becomes white hot.

Most of the electrons in the bundle of cathode rays strike a limited portion (1 sq. cm.) of the target called the focal spot which is usually visibly defined as a pitted or etched area on the target face. This spot is determined by the shield of molybdenum around the filament; the deeper in the cylinder, the smaller the bundles. The great heat generated in the target without extraordinary cooling is explained by the following example of the energy involved. At 200 kilovolts and 3 milliamperes the kinetic energy of the electrons moving at 220,000 kilometers per second is 150 cal./sec. or enough energy in 10 minutes to raise a liter of water from 10°C. to boiling. Only about 2 per cent of this energy is transformed into x-radiation and the remaining 98 per cent goes into heat.

Obviously only metals can be used for targets which will not melt under these conditions, and such tubes cannot automatically rectify alternating voltages since both electrodes are hot and are, therefore, sources of electrons. For intermittent use special radiators for air cooling are fixed on the end of the target arm; for continuous operation and for loads above 1 kilowatt, water cooling of the target is resorted to. When the target is kept cold, the terminals of the high-tension transformer producing low or moderate alternating voltages may be attached directly to the Coolidge tube, for it is then self-rectifying. Current will flow only during the half-time period during which the hot wire is negatively charged with respect to the target. If the target is cold (during the time it is negative), there are no electrons available for the reverse current.

One great advantage of the Coolidge tube is the independence of the current through the tube and the voltage. One may be altered without affecting the other, while in gas tubes it is obvious that the number of the electrons, and hence the current, will increase with the voltage. The current in the former type depends upon the number of electrons N, and this in turn depends upon the temperature of the hot-wire filament, by the Richardson relationship $N = CT^2 e^{-d/T}$, where C and d are constants depending upon the metal (1.86×10^{11} and 4.95×10^4, respectively, for tungsten), and T is the absolute temperature. On account of the building up of a space charge, since the tube current does not increase as rapidly as does the number of electrons when the temperature of the filament is increased but the voltage held constant, a maximum or saturation current is reached at a point expressed by the equation deduced by Langmuir:

$$i_{max} = \frac{\sqrt{2}}{4\pi} \sqrt{\frac{e}{m}} \frac{V^{3/2}}{x^2}.$$

Here e and m are the charge and the mass of the electron, V the voltage, and x the distance between electrodes. This relationship has enabled investigators to predict correct design for tubes.

It is not of primary concern here to discuss all the numerous modifications of roentgen tubes which have appeared since the original Coolidge tube. Of special interest as far as the cathode and the cathode-ray stream is concerned are the following:

(*a*) Numerous devices to focus the cath-

ode-ray stream as it impinges on the target, broad (for deep therapy), medium, and fine (for diagnostic roentgenograms).

(*b*) "Dofok" tubes have two hot spirals in the cathode, the one for fine focus and lower loads, the other for larger focus and higher loads.

(*c*) Tubes with elongated focal spot for fine focus but high intensity. The desire to increase the load and intensity of roentgen radiation from such tubes in order to cut down exposure time to a minimum is opposed by the fact that greater energy input in a small focal spot results in melting and destruction of the target. Increase in size of the focal spot in all directions causes diagnostic photographs to lose sharpness. Hence, it is necessary to change the focus so that the cross section through the roentgen-ray bundle at the focal spot is as small as possible. The line focus filament of Goetze employed in the Media tubes of Müller is a successful solution. A long cylindrical spiral of very small diameter produces a line focal spot on the target which by virtue of length takes up a very considerable amount of energy without damage to the target. The face of the target is inclined at an angle of 80° to the tube axis so that the line focal spot in the principal direction of emergence of the roentgen rays appears foreshortened to a spot 2 mm. square. The 10 kw. Media tube is rated at 250 ma. at 40 kv. effective for 1 second or 370 ma. at 40 kv. for 0.1 second. Two line focus filaments at right angles are used in still newer cross focus tubes, particularly for diffraction tubes in which four windows enable four simultaneous exposures from the same tube.

(*d*) Hot cathodes may still be used and the tube function as an electron tube in the presence of certain gases. The Müller tubes contain helium and the Westinghouse tubes neon. These gases which are admitted after the tubes are exhausted and degassed do not disappear or "clean up" upon operation of the tube like air and the high ionization potentials prohibit action as ion tubes while at the same time they permit pressure and operation to remain constant over long periods of time.

(*e*) Of especial interest are the recent tubes operating at very high potentials, in which problems of insulation seem almost insurmountable. Of these the most sensational is that of Lange and Brasch. The tube, only about a meter long was built up of successive rings of varying diameters of pipe and rubber. The cold cathode was actually a cylinder of porcelain (an insulator) from which electrons were pulled at potentials of nearly 3 million volts. The interest in such tubes lies in the possibility of producing γ-rays in intensity corresponding to that from millions of dollars of radium.

(*f*) The cathode-ray tube of Coolidge is already generally familiar. The beam from a hot filament passes through a thin foil window into the outer air where numerous properties and effects have been studied, including excitation to luminescence, and intense coloration of substances, effect upon various chemical reactions, and effects upon tissues, seedlings, etc. The electrons are accelerated to a velocity corresponding to 900,000 volts by the cascade system of 300,000 volts each. This is now being employed with roentgen-ray tubes to operate at 900,000 volts also (for example, at the Memorial Hospital in New York City).

One new application of the cathode-ray tube has been for quantitative chemical analysis. A substance is bombarded with the stream of electrons outside the tube. The secondary fluorescent roentgen rays (characteristic of each chemical element in the samples) generated as a result, are analyzed spectrometrically.

Happenings to an Electron in a Roentgen-ray Tube.—Roentgen rays are produced when the atoms in a target are bombarded by a stream of electrons. Assuming for the moment that the atom is built from a positively charged nucleus surrounded by electrons in various energy levels or moving in orbits, it is now clear that at least four things can happen to an electron which is hurled at the anode in a roentgen tube:

(1) It can be reflected from the anode surface.

(2) It can pass through one or more atoms. The electric fields on the interior of the atom diminishes the speed of the electron so that it loses part of its energy. This has been imparted to the atom whose kinetic energy is increased; thus the lost electron energy has been transformed into *heat* and the temperature of the anode rises. The slowed-up electron then may pass through another atom with further diminution in speed and so on until it is stopped.

(3) It is stopped completely by impact with the atom nucleus. In this case only is the electron energy transformed completely to radiation with a continuous spectrum. The stoppage in steps explains why from a roentgen tube operating at absolutely constant potential rays of different wave-lengths are emitted. It is evident that roentgen rays are generated not only upon the surface of the anode but also in the interior of the metal. The thickness of the layer in which roentgen rays arise depends on the voltage and on the anode material; with a tungsten target this is only about 0.001 mm. or a layer 2000 tungsten atoms deep.

(4) During passage through the atom it may force an electron out of its energy level (or quantum orbit) either to another level, thereby producing an excited atom, or entirely out of the atom in the anode atom now ionized thereby losing a definite part of its own energy. It proceeds with smaller kinetic energy to any one of the four possible occurrences. This process results in the production of characteristic roentgen rays.

SCATTERED ROENTGEN RAYS MODIFIED BY THE COMPTON EFFECT

One of the great contributions in physics in recent years was the discovery by Compton and by Debye that the spectra of scattered rays, characteristic of the primary rays and not of the secondary radiators, show not only lines with the same wave-length as those in the primary beam, but on the long wave-length side of these lines, other lines which indicate that in the process of scattering a distinct change has occurred. These modified lines were shown to be quantitatively explained upon the basis of a purely quantum phenomenon. A primary quantum of x-radiation with energy $h\nu_0$ strikes an electron and imparts to it a certain amount of kinetic energy resulting in recoil. The radiation quantum is changed in its direction and proceeds with an energy $h\nu$ smaller by the amount involved in the recoil of the electron. Consequently the wave length will be longer. The so-called shift from the unmodified wave length is expressed by the equation $\delta\lambda = (2h/mc) \sin^2 \phi/2 = 0.0484 \sin^2 \phi/2$, where ϕ is the angle between the incident and the scattered ray. At $\phi = 90$ deg., the shift will therefore be 0.0242Å. This increase in wave length is, therefore, independent of the wave length and of the scattering element, and depends only on the angle ϕ. The ratio of the intensities of modified and unmodified rays in the Compton effect, however, varies with the atomic number of the radiator element, from ∞ for lithium (all energy modified), to 5.48 for carbon, 1.91 for sulfur, 0.51 for iron, 0.21 for copper and decreasing values for heavier elements to practically zero for lead. The Compton effect has been the subject of considerable controversy, as the result of which careful researches by numerous investigators throughout the world have established it as a fact and as a powerful support to the conception of radiation energy in quanta. As independent proof the tracks of the recoil electrons have been photographed by C. T. R. Wilson's cloud-expansion method. No such change in wave length has been observed in the reflection of roentgen rays by crystals, or in the scattering of rays of light.

It is interesting to calculate how much energy is involved in the recoil electrons for a practical case of irradiation of the human body from a tube at 200 kv. (av. wave length 0.04Å).

$$E_{\text{kinetic}} = h(\nu_0 - \nu).$$

If the average increase in wave length ($\phi = 90°$) is 0.024Å,

$$E = h\left(\frac{c}{\lambda_0} - \frac{c}{\lambda_0 + 0.024}\right);$$

expressing E in volts the recoil electrons have a velocity of about 50 kv. Thus 50/200, or 25 per cent, of each quantum in the human body goes into the energy of recoil electrons. For rays generated at 200 kv., 2.5 per cent of the roentgen energy in each part of a tissue is transformed into the energy of photoelectrons. Of the fraction of primary energy which is scattered (12 per cent), 3 per cent (25 per cent of 12 per cent) goes into recoil electron energy.

SCATTERED AND CHARACTERISTIC β-RAYS

Roentgen rays which are impinging upon the surface of a secondary radiator eject photoelectrons. If the radiation is monochromatic (frequency ν) then the velocity of some of the liberated (scattered) electrons will be $\frac{1}{2}\,mv^2 = h\nu$, independent of the secondary radiator. The electrons are those so loosely bound in the atoms that the work required for their removal is negligible. In addition, however, other photoelectrons are ejected with velocities which depend upon the particular kind of atom from which they are liberated: hence, their removal has involved a certain amount of work W. If a beam of these electrons is analyzed by causing them to bend in a magnetic field, then all electrons with the same value of $\frac{1}{2}\,mv^2 = h\nu - W$ will register a sharp spectral line on a suitably disposed photographic plate. By means of these characteristic β-ray spectra de Broglie showed that the energy necessary to eject an electron from an inner atomic shell which is involved in the correction term W, is simply the quantity of energy representing the energy levels K, L, M, N, etc., which is in turn measured by the frequency values of the critical absorption limits. These β-ray spectra, therefore, constitute another important method of measuring energy levels. In one photograph for photoelectrons ejected from a silver plate irradiated by the K-radiation of tungsten (and of course producing the secondary fluorescent silver K-radiation), de Broglie obtained six lines, corresponding to six different velocities. He showed that these were:[1]

$\frac{1}{2}\,mv_1^2 = h\nu_{W-K\beta} - h\nu_{Ag-K\text{abs.}}$;
$\frac{1}{2}\,mv_2^2 = h\nu_{W-K\alpha 1} - h\nu_{Ag-K\text{abs.}}$;
$\frac{1}{2}\,mv_3^2 = h\nu_{W-K\alpha 2} - h\nu_{Ag-K\text{abs.}}$;
$\frac{1}{2}\,mv_4^2 = h\nu_{Ag-K\beta} - h\nu_{Ag-M\text{abs.}}$;
$\frac{1}{2}\,mv_5^2 = h\nu_{Ag-K\beta} - h\nu_{Ag-L\text{abs.}}$;
$\frac{1}{2}\,mv_6^2 = h\nu_{Ag-K\alpha 1,2} - h\nu_{Ag-L\text{abs.}}$;
and $h\nu_{AgK\alpha 1,2} - h\nu_{Ag-M\text{abs.}}$

THE BOHR THEORY OF ATOMIC STRUCTURE

Before outlining very briefly the Bohr theory of atomic structure by means of which a very useful mechanical model could be constructed and processes related to radiation clearly pictured, it must be frankly stated that it is deficient and unable to meet the demands of the newest experimental physics. However, new quantum or wave mechanics in which the atom is a mathematical equation have not advanced as yet to the stage where any very satisfactory explanation can be given to the above facts of roentgen-ray spectra. Hence the Bohr theory of the planetary atom still is worthy of presentation and use as a qualitative tool particularly as it utilizes fundamental quantum laws. Sir William Bragg advises that science must not be criticized for dropping one theory in favor of another, as a carpenter is not scolded for dropping his saw to use his chisel. In a word, science can neither believe wholly in the Bohr atom nor do without it.

In addition to some of the experimental facts of roentgen-ray spectroscopy, there were in 1916 four other great factors, which were largely unrelated and even discrepant, to be taken into consideration by any theory. These were: the classical electromagnetic (wave) theory of radiation, the Planck quantum theory of radiation, the Rutherford nuclear atom, and the empirical (optical) spectroscopy of Balmer, Ritz, and Rydberg. The last factor refers to the unexplained relationships such as the follow-

[1] For further detailed information see International Critical Tables, Vol. 6, p. 2.

ing for the optical series of hydrogen: Lyman series,

$$\nu_1 = \nu_0\left(\frac{1}{1^2} - \frac{1}{n_1^2}\right),\ n_1 = 2, 3, 4, \cdots;$$

Balmer series,

$$\nu_2 = \nu_0\left(\frac{1}{2^2} - \frac{1}{n_2^2}\right),\ n_2 = 3, 4, 5, \cdots;$$

Paschen series,

$$\nu_3 = \nu_0\left(\frac{1}{m^2} - \frac{1}{n_3^2}\right),\ n_3 = 4, 5, 6, \cdots;$$

etc., or in general

$$\nu = \nu_0\left(\frac{1}{m^2} - \frac{1}{n^2}\right).$$

The fundamental foundation blocks of the original Bohr theory are as follows:

1. The atom consists of a positively charged, extremely minute nucleus which accounts for practically all the mass, and of negative electrons as satellites. The number of these electrons is equal to the net positive charge on the nucleus, and this number is the atomic number. The table of elements is constructed by the addition of one net positive charge and one non-nuclear electron for each element, beginning with hydrogen with one positive charge on the nucleus and one electron.

2. The atom is a dynamic system, for the electrons are in rapid orbital motion.

3. Three laws govern this atom:

a. An Acceleration Law.—The coulomb force of attraction between positive and negative charges is opposed by the centrifugal force required to keep the electrons revolving in a circle; in other words $e^2/a^2 = mv^2/a$, where e is the electric charge (+ or −), a the distance between two charges, m the mass of the electron, and v its velocity.

b. A Momentum Law.—The angular momentum is governed by the equation $mva = nh/2\pi$, where n is an integer, and h is a constant. In other words, the motion of the electron is very definitely restricted to orbits whose angular moment multiplied by 2 is equal nh. The possible configurations under this quantum condition are called stationary states because no radiation is emitted while the atom remains in such a state.

c. A Frequency Law.—While an electron is revolving in any definite orbit of definite energy W_1, it is conceived to be non-radiating, for otherwise energy would be lost and the electron would be pulled gradually into the nucleus. Another orbit W_2 would correspond to a different energy level. It is only in the process of transition of an electron from one orbit to another that radiation may be emitted or absorbed; in other words, the energy difference $W_1 - W_2 = h\nu$, where ν is the frequency of the radiation and h the Planck action constant. Ordinarily an atom exists in the stationary state of lowest energy but by absorption of radiation or some kinds of collisions it may be "excited" to a higher energy state. Radiation is emitted during the transition from a higher to lower state of energy.

A combination of these simple laws gives the equation

$$\nu = \frac{2\pi^2 e^4 m}{h^3}\left(\frac{1}{m^2} - \frac{1}{n^2}\right),\ \text{or}\ \nu = \nu_0\left(\frac{1}{m^2} - \frac{1}{n^2}\right)$$

where ν_0 is a fundamental constant frequency, the Rydberg constant already mentioned, and m and n whole numbers; the equation expresses the frequencies of the spectral lines of hydrogen. There is thus immediate explanation for the empirical spectroscopic formulas of Balmer, Ritz, and Rydberg.

Since the simple Bohr theory of hydrogen was announced, many corrections and additions have been made. Briefly enumerated these are as follows:

1. Allowance for the mass of the nucleus (in ionized helium the mass 4 must be introduced).

2. Allowance for the revolution of the nucleus around the common center of gravity.

3. A relativity correction, taking into account the variation in mass with the velocity of electrons.

4. The introduction of elliptical orbits, in addition to Bohr's circular ones, to ac-

count for the fine structure of spectral lines. These orbits, in order to have slightly different energies than the circular ones and thus to account for the complexity of apparently single lines, must undergo precession around the nucleus.

5. The most striking characteristic of the quantum theory of atomic structure is the frequent occurrence of integers and half integers; it is essentially a theory of numbers which are combined in all possible ways. The types of elliptical orbits, upon which the electrons in the complicated atoms revolve, may be characterized by quantum numbers n, k, j. The number n is related to the size of the orbit, k to its shape, and j to its position in the atoms relative to other electronic orbits. For convenience a particular orbit is referred to as n_{kj}. The larger the value of n, the more loosely is the electron bound to the atom. Thus the innermost electron "shell" consists of a single circular orbit 1_{11}, the second of two ellipses 2_{11} (most eccentric), and 2_{21}, and a circle 2_{22} and so on. A third subquantum number takes into account electron spin.

6. By combination of roentgen-ray, spectroscopic, and chemical information the complete arrangement of electrons in various shells or orbits has been derived, most satisfactorily in 1925 by Stoner and Main-Smith, for all the elements from hydrogen to uranium. As an example may be cited the structure for the rare gases of the atmosphere, which, except helium, always have eight outside electrons:

2. He $1_{11}(2)$.

10. Ne $1_{11}(2)$; $2_{11}(2)$; $2_{21}(2)$; $2_{22}(4)$.

18. A $1_{11}(2)$; $2_{11}(2)$; $2_{21}(2)$; $2_{22}(4)$; $3_{11}(2)$; $3_{21}(2)$; $3_{22}(4)$.

36. Kr $1_{11}(2)$; $2_{11}(2)$; $2_{21}(2)$; $2_{22}(4)$; $3_{11}(2)$; $3_{21}(2)$; $3_{22}(4)$; $3_{32}(4)$; $3_{33}(6)$; $4_{11}(2)$; $4_{21}(2)$; $4_{22}(4)$.

54. Xe, same as Kr and in addition $4_{32}(4)$; $4_{33}(6)$; $5_{11}(2)$; $5_{21}(2)$; $5_{22}(4)$.

86. Rn same as Xe, and in addition $5_{32}(4)$; $5_{33}(6)$; $6_{11}(2)$; $6_{21}(2)$; $6_{22}(4)$.

This system explains all known chemical and spectroscopic facts, the similarity in such homologous elements as Li, Na, K, Rb, and Cs, the chemical similarity of the triads Fe, Co, Ni; Ru, Rh, Pd; and Os, Ir, Pt; and the place of the 14 rare earths (57–71). Here the successive electrons are added in the 4_{43} and 4_{44} orbits, previously unoccupied, though electrons are being added in the fifth shell beginning with rubidium, atomic number 37.

The Bohr theory, therefore, explains the facts of roentgen-ray spectra as follows:

1. Critical Absorption Limits.—Energy required in primary radiation quantum, or collision with cathode rays, to lift electrons from a given energy level out of atom.

2. Critical Ionization.—The frequency is the same as that of critical absorption, since only with energies greater than corresponding to this frequency can ionization and electric current increase occur.

3. Sharp Emission Lines in Series.—When a K electron is removed, L electrons may fall into the vacancy producing $K\alpha_1$ and $K\alpha_2$ (possibly $K\alpha_3$) from the three L levels corresponding to circular and elliptical orbits. The $K\beta$ doublet results from the transition of electrons from two of the five M levels, and $K\gamma$ from transition from an N level. If electrons in the L level are removed, the L series results by the transition from the higher M, N, etc. levels to the L level. With three L and five M levels there are thus possible 15 lines from this one type. However, not all the lines appear. The spectra are governed by a partly empirical principle of selection which states that n in the quantum number n_{kj} must change, and that k must change by one unit or not at all. Energy-level diagrams have been constructed already for all the atoms to show how spectral lines in roentgen-ray and optical regions are related to these transitions. Optical spectral lines are produced, of course, by electronic changes between the orbits farthest removed from the center.

4. Critical Excitation Potentials.—The K series lines are not excited separately but appear together only when the K electron can absorb the energy from the exciting

cathode rays which must correspond at least to $Ve = h\nu_{K-abs.}$ or from an exciting primary roentgen ray passing over an atom with a frequency of $\nu_{K-abs.}$ or greater. Only under these conditions is it possible to impart sufficient energy to the K electron to remove it entirely from the atom (not to the L or M levels, for example). The vacancy is supplied then by an L, M, or N electron; the new vacancy is filled from a still more distant ring. The electrons thus fall back into the K ring by a process which, to a certain extent, takes place as a series of steps; but jumping over several steps and even the direct return of an outer electron to the K ring is not unusual.

5. The Moseley law (the values of $\sqrt{\nu}$ for a given spectrum line plotted against atomic numbers of chemical elements used as targets be on a straight line) is a consequence of the fact that the innermost levels in atoms, which affect roentgen rays, are all similarly constituted in number and disposition of the electrons.

6. The combination principle is a direct consequence of different energy levels with definite values. The same wave-number difference may be obtained by several combinations of the wave numbers of critical absorption limits and emission lines, when these are pictured as distinct jumps from lower to higher levels or vice versa. The principle thus affords several checks for numerical evaluation of the energy levels.

ROENTGEN RAYS AND THE NEW QUANTUM THEORY

Heisenberg cites as the most important experiments from which may be induced concepts of present physics the following:

a. Wilson photographs by the cloud track method showing that α and β rays may be regarded as streams of minute particles.

b. Diffraction of β rays, or electrons showing wave-like properties discovered by Davisson and Germer in 1927.

c. The diffraction of roentgen rays showing form of wave-motion, and the photoelectric ejection of electrons, when roentgen rays strike matter, showing corpuscular properties.

d. The Compton-Simon experiment in which roentgen rays passing through supersaturated water vapor are scattered by molecules, producing both recoil electrons and photoelectrons, the first by a collision of a photon (light particle) with an electron in a molecule and the second as a result of the collision of this photon moving in a new direction with a second molecule.

e. Collision experiments of Franck and Hertz leading to the conclusion that atoms in a gas through which a beam of slow electrons passes can assume only discrete energy values and "stationary states" as originally postulated by Bohr.

In simplest terms the essential facts involved underlying the new theories which have displaced the Bohr model are as follows:

(1) Matter, *including free electrons*, and radiation possess a remarkable duality of character, as they sometimes exhibit the properties of waves, at other times those of particles. A thing cannot be a form of wave motion and composed of particles at the same time. It is experimentally certain only that light sometimes behaves as if it possessed some of the attributes of a particle, but there is no experiment which proves that it possesses all the properties of a particle; similar statements hold for matter and wave motion.

(2) Language is incapable of describing processes occurring within atoms for it was invented to express the experiences of daily life which consist of processes involving exceedingly large numbers of atoms. Furthermore it is almost impossible to modify it so as to describe these atomic processes for words can only describe things of which we can form mental pictures and this ability is a result of daily experience. Mathematics is not subject to this limitation.

(3) Contradictions between theory (Bohr) and experiment have led to the necessity of demanding that no concept enter a thing which has not been experimentally verified.

(4) The principle of uncertainty shows among other things that the position and velocity of an electron (say in an orbit) cannot be known simultaneously. Determinism is dropped out of the latest formulations of theoretical physics.

(5) The new theory removes discrepancies between the orbit theory and facts of spectroscopy, particularly fine structure. The power of the new quantum mechanics in giving better understanding of events or at atomic scale is becoming increasingly evident. The structure of the helium atom, the existence of half quantum numbers in band spectra, the continuous spatial distribution of photoelectrons and the phenomenon of radioactive disintegration are items which baffled old theories but are successfully achieved by the new.

(6) As nearly as may be visually conceived the new model of the atom spreads the electron from a point charge moving in orbits to diffuse shells of negative electricity with increasing density the closer to the nucleus. Hence the orbits are smudged, in the words of G. P. Thomson, but the electrons retain in a sense their individuality. However, Dirac regards waves or particles of light or electrons as two useful abstractions for describing the same physical reality but he warns the student against combining them into a mechanism that behaves like familiar things.

(7) The Bohr atom is, therefore, welcomed today as an indispensable model, expected to remain so for many years to come and admitted to be inadequate. Even the most advanced mathematical physicists still speak of "orbits" and "electron jumps." Nor has the final word been said with the new mathematical models.

(8) Finally, in the words of Jeans, "the Great Architect of the Universe now begins to appear as a pure mathematician."

THE MECHANISM OF CHEMICAL AND BIOLOGICAL ACTION

It is evident that absorption of radiation energy must precede any physical chemical or biological effects which may be observed. In pure absorption the energy of a roentgen-ray quantum is transformed to that of electrons (photoelectrons) liberated from atoms, together with the net potential energy of the irradiated atom (ionization). In the latter case, the atom remains in the ionized condition only a very short time (10^{-9} seconds); one of the electrons in the outer orbits falls into the vacancy created by the photoelectron. In so doing the potential energy of the ionized atoms becomes the energy of secondary characteristic rays. The ionized atom, by virtue of its changed condition, can also enter into chemical reactions. Since secondary characteristic rays produced by return of the ionized atom to the normal state are softer than the primary rays, especially so in the human body on account of the light elements, they will be easily absorbed by one of two processes. The quantum of radiation may leave the mother atom and be absorbed by a neighboring atom, or it may actually remain in the mother atom so that its energy is used for the liberation of a second electron (photoelectron of the second kind). This effect or process of inner absorption can also be considered as a radiationless transition of an electron to a deeper orbit, in which the energy difference is imparted as kinetic energy to another electron.

The photoelectrons account for the second portion of the energy following absorption of a primary quantum (or roentgen-ray photon). The variations in velocities as determined in β-ray spectra have already been considered and it follows that the kinetic energy will have nearly the same value of the primary roentgen-ray quantum for light elements or for outer electrons of heavier atoms, in which the work required to free the electron is small. The photoelectron is now free to liberate secondary electrons by impact with atoms, which of course have lower velocities, thereby ionizing the atoms; or the impact may serve only to lift the electron to a higher energy level in the atom which becomes therefore excited.

Still another mechanism in the absorp-

tion of roentgen rays by atoms in molecules is of course the transformation into heat. An increase in energy of motion of atoms in molecules in position results is nothing more than local elevation in temperature. Of course, in an irradiated body the transformed roentgen-ray energy is so small that a measurable increase in temperature is almost impossible to observe. The phenomenon is of interest in the light of Dessauer's point-heat theory of biological action.

It is certain that in a biological or chemical medium the photoelectrons possess large initial velocity with a velocity distribution corresponding to the roentgen-ray spectrum. The fate of the photoelectrons is of course widely varied but in general it is the same as that observed for the impact of cathode rays on the anticathode of the roentgen tube. Between the first and last (heat) steps in the chain of transformations the widest variety of effects may be possible.

These high speed electrons of course can bring into reactive form by impact other atoms and molecules which have been absolutely unaffected by the primary radiation quanta; in fact the proportion of atoms and molecules activated by the photoelectrons may be very much larger. This mechanism differs from the chemical effects of ordinary light in which energy suffices only to excite atoms by lifting electrons to higher energy levels. Roentgen rays also differ from ordinary light in that they may have chemical action and yet be unabsorbed (scattering and recoil electrons), a process unknown for light.

Besides the process of true absorption, the energy of a quantum of x-radiation can also be transformed into electron kinetic energy—that of the recoil electrons in the Compton effect. The velocity of these is considerably smaller than that of the photoelectrons and of course depends on the scattering angle. Their chemical and biological effects are consequently smaller. However, it must be noted that at 200 kv. 2.5 per cent of the roentgen-ray energy goes into photoelectrons and 3 per cent into recoil electrons. At higher voltages the latter figure becomes even more significant.

EXPERIMENTAL TESTS OF THEORIES OF CHEMICAL REACTION MECHANISM

The above theory of chemical action due very largely to Glocker has been subjected by him and by others to experimental test. Glocker and Risse have studied the decomposition of hydrogen peroxide and potassium persulfate, in very dilute solutions. The amounts decomposed corresponded to the energy of the secondary electrons liberated in the system during passage of roentgen rays; 70,000 cal. (electrons in motion) are required to decompose 1 mole of H_2O_2 in 1/600 normal solution and 2.45 times as much for potassium persulfate. The dependence of chemical effect upon roentgen-ray wave length is a question entirely of how much energy during passage of a roentgen beam of certain wave length through matter of certain composition is transformed into the energy of secondary electrons. Taking into account the complications of scattered and fluorescent rays which may form secondary electrons, Glocker and Risse have obtained complete verification of the theory and further substantiation has been obtained by other workers for other systems.

In general, the exact mechanism and kinetics of chemical reactions, though due to activation by electron impact, has been explained only in a very few instances. The photographic action is unusually simple in that the silver and bromine ions are converted endothermically into neutral atoms through the energy of the secondary electrons. The evolution of hydrogen chloride from chloroform is the best example of a reaction where far greater change is observed than can be accounted for by electron impact. It is, therefore, a chain reaction: a residual chloroform molecule disturbed by electron impact can react with an unchanged chloroform molecule. The product of this reaction with another unchanged chloroform molecule and so on. Such reac-

tions together with side reactions with atmospheric oxygen account for the extreme sensitiveness towards roentgen rays of iodoform solutions in chloroform. Because of the common mechanism some chemical effects of roentgen rays would be expected to be the same as those with ultraviolet light, but not necessarily the same as thermal reactions. Barium azide decomposes into nitride with roentgen rays but never with heat.

GENERAL SUMMARY

The foregoing brief discussion of some topics in electron physics serve to show the complexity and remarkable mechanisms fundamentally involved in every phase of the work of the roentgenologist. In his roentgen tubes are involved all the laws and theories of the electron, its emission from solids, its passage through gases at reduced pressures and the intimate relationship between the kinetic energy of the electron when it impinges upon matter and the resultant four-fold possibility as to what happens to it, including emission of radiation. The roentgenologist uses radium in cancer treatment because electrons are spontaneously hurled out by disintegrating atoms. He treats cancer with roentgen rays because he knows the therapeutic value though he may not realize that the effective agent is not the radiation but the photoelectrons and recoil electrons liberated from the atoms of the human body when roentgen rays pass over them. Every single treatment, every moment of operation of apparatus, every physical, chemical and biological effect, involves the fundamental principles of electron physics, which are still imperfectly known. Upon a knowledge of these principles the progress of roentgen-ray science has depended and must depend for correct design of equipment, correct dosage and the greatest measure of effectiveness in promoting human welfare. The coming quarter century will undoubtedly witness even greater research achievements and closer cooperation between the physicist, chemist, biologist and roentgenologist in coming to an understanding of both purely scientific and practical aspects of such a fundamental unit in the universe as the electron, whether it be a corpuscle, a wave, or both, or neither.

THE HISTORICAL EVOLUTION OF ROENTGEN-RAY PLATES AND FILMS

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"Of especial interest in many ways is the fact that photographic dry plates show themselves susceptible to x-rays. We are thus in a position to corroborate many phenomena in which mistakes are easy, and I have, whenever possible, controlled each important ocular observation on fluorescence by means of photography."

THE above quotation from the preliminary communication of W. C. Roentgen, "On a New Kind of Ray," paragraph 6, December, 1895, is significant since it indicates that the importance of the photographic plate as a means of recording the roentgenographic image was recognized immediately. He demonstrated this point by showing the first roentgenogram of a hand and also the first roentgenogram taken through metal, which showed a compass card and needle enclosed in a metal case.

To produce a satisfactory roentgenogram was then difficult, often distressingly impossible, for the photographic plate then available and designed for exposure to light was affected by only a very small proportion of the x-ray energy that fell upon it. Nowadays special emulsions containing as many silver grains as possible are used in order to obtain the maximum effect.

In reviewing early x-ray literature, one is frequently impressed with the remarkable results shown in the reproductions of roentgenograms secured by some of the pioneer workers with no more elaborate equipment than an induction coil, a gas tube, and a portrait plate—a combination which required an exposure in the beginning of one or more hours to roentgenograph the hand. Were it possible to compare an early roentgenogram with a modern one, it would be strikingly evident that the image in the former lacked density and contrast. However, since at that time it was a general practice to print all roentgenograms on sensitive paper, this was not a serious handicap, for a more satisfactory print could be secured with greater ease from a roentgenogram of the above type than from a present day roentgenogram in which differences in detail are recorded with considerable contrast. As a matter of fact, the roentgen image secured in the early days was frequently so faint, regardless of the length of exposure, that after-treatment of the negatives was often necessary in order to make satisfactory prints.

It is not without cause that all x-ray experimenters of that time clamored for greater speed in photographic sensitive materials. The echo of this clamor has even reached the present day, for there still appears to be a common insistence that the manufacturers produce a film of still higher sensitivity, even though apparatus and tubes have been developed to their present day efficiency.

The need for greater photographic sensitivity led experimenters to try all manner and means of increasing the speed of their photographic plates. They heated the plates before exposure to lower the time—plenty of fog resulted, but no increase in the density of the image was obtained. A few of the other efforts made were the impregnation of x-ray fluorescent salts in the emulsion, dipping the dry plate in solutions of fluorescent salts and then drying. However, Edison's improvement of the fluorescent screen by using calcium tungstate crystals instead of platino-barium-cyanide crystals offered for a time a panacea to the puzzled workers.

In the *Photographic Times* of March, 1896, one may read what was perhaps the

first description of the use of a fluorescent screen in conjunction with a plate to shorten exposure:

A striking experiment made by Prof. Pupin. . . . It occurred to Dr. Pupin to paint the back of the plate shutter with luminous paint, or to dip the sensitized plate in a fluorescent substance. His idea was, and the first preliminary experiment seems to be promising, that the energy from the Roentgen rays would undergo a retransformation behind the plate shutter, and, by becoming luminous mark a greater contrast between light and shadow.

Reading further in Prof. Pupin's book from "Immigrant to Inventor," we find:

My good friend, Thomas Edison, had sent me several fluorescent screens, . . . I decided to try a combination of Edison's fluorescent screen and the photographic plate. The fluorescent screen was placed on the photographic plate and the patient's hand placed on the screen. . . . The combination succeeded even better than I had expected. A beautiful photograph was obtained with an exposure of a few seconds. . . . That was the first x-ray picture obtained by that process during the first part of February, 1896, ...

Further work on the fluorescent screen tended to over-emphasize the idea that all x-ray work could be satisfactorily performed by means of the fluoroscope. This idea was substantiated in some degree by a telegram given wide publicity, which Edison sent to Lord Kelvin in March, 1896—"Just found calcium tungstate properly crystallized gives splendid fluorescence with Roentgen rays, far exceeding platinocyanide, rendering photographs unnecessary."

Subsequent events, however, have proved the fallaciousness of this hasty assumption.

While the more brilliant visual image of Edison's new fluorescent screen of calcium tungstate (1896) was some improvement over the earlier type of screen yet it still had many disadvantages. In the examination of the thicker parts of the body, the image was difficult to decipher because of its grain; detail, even in the thinner parts, was almost impossible to discern. There were advantages that were realized by the majority in favor of the photographic plate for it provided not only a permanent record but a clearer one with greater definition and a minute detail which was unobtainable by an examination utilizing the fluoroscopic screen. Further, the effect of the roentgen rays on the sensitive plate was cumulative so that a screen image, only faintly perceptible, could be more satisfactorily registered on a plate by merely prolonging the exposure. In this way roentgenograms of an adult pelvis could be made, yet such an image was beyond the capabilities of the eye when observed on the screen.

In Roentgen's original paper, it was pointed out that either plates or films might be used:

It is still open to question whether the chemical effect on the silver salts of photographic plates is exercised directly by the x-rays. It is possible that this effect is due to the fluorescent light which, . . . may be generated on the glass plate, or perhaps in the layer of gelatine. Films may be used just as well as glass plates.

The reduction in the time of exposure was one of the early problems to be met with for it was realized that if this "new photography" was to be of any value, prolonged exposure was entirely out of the question. So up to May, 1901, no very startling improvement was made in the manufacture of plates, and the consensus of opinion was that any good brand of very fast photographic plate gave results in keeping with the best efforts of the roentgen-ray workers. Various opinions were decidedly conflicting. Some claimed that a plate, slow to light, was fast to roentgen rays and vice versa. The majority leaned to the opinion that the fast plate to light was correspondingly fast to roentgen rays.

Prior to May, 1901, plates most suitable for roentgenography seemed to be the English, "Cadett Lightning," "Paget xxxxx," "Imperial" flashlight (May 1896), and "S.W." Roentgen Plates, Sandell Works Co.; the French, "Lumiere" (1896), and the American, Cramer "C" Plate, June, 1896. At this time Eastman Transparent

film—New Formula, was being manufactured and used by some in a limited way for roentgen-ray purposes just as were other photographic films and plates. The recommendation usually advanced by many of the best workers was to use a plate which the roentgenographer understood. This recommendation was so widely accepted that it tended to delay whatever efforts manufacturers were willing to make in producing a special roentgen-ray emulsion. As long as the consumer was content with the photographic plate, it was apparently thought advisable to let well enough alone.

One of the difficulties in development was to obtain the proper amount of density. The roentgenograms were apt to be "thin" and lacking in contrast. To overcome this difficulty and at the same time to decrease the time of exposure, multi-emulsion coated plates and films were made for it was claimed that greater detail and contrast was obtained as compared to a single coated plate or film. Special plates and films were also coated on both sides of the support. The rays passed through the support and in the case of film affected the emulsion on each side in the same degree so that the image on one side reinforced that of the other. This method has today doubled the density of the image and hence improved the roentgenogram's diagnostic value.

Because of the then prevalent method of x-ray development, such coated sensitive material was difficult to develop, but the roentgenographers of those days were used to the complicated, and non-standardized photographic methods, and accepted the attendant difficulties with little thought of possible simplification.

Films, even then, had some advantages over plates for they were not liable to break as would a plate. The disadvantage, however, lay in their tendency to bend and wrinkle, thereby leading to distortion of the image. Films used for roentgen-ray purposes in England prior to 1901 were the Austin-Edwards' snapshot film and the "Cristoid" made by the Sandell Plate Company. The latter films were essentially gelatine not cellulose, and were made of two emulsions—one very rapid and one of regular speed—coated on glass and then stripped off. The films were supplied packed in dark envelopes, were difficult to develop and much slower than fast plates.

The "Cathodal Plate" manufactured in England by B. J. Edwards and Company about May, 1896, was an improvement over the usual photographic plate in that the suggestion of Sir Oliver Lodge was adopted which required that a fluorescent substance be incorporated with the emulsion.

There had been extensive experimentation with emulsions in America, and roentgenographers went through pretty much the same dilemma as the English. No improvement in photographic plates or films for roentgen-ray purposes was attempted until John Carbutt cooperating with Professor Goodspeed of the Physical Laboratories of the University of Pennsylvania succeeded in manufacturing an emulsion especially sensitive to roentgen rays.

This special emulsion permitted a radical reduction in the time of exposure. It was first tried out on February 11, 1896, at the Maternity Hospital, Philadelphia, Pennsylvania. Prof. Magie made the first exposure on a patient of Dr. W. W. Keen's who had an ankylosis of the finger joints caused by a burn, the exposure being twenty minutes. Previously such exposures were from one or more hours in duration. With further improvement in apparatus and roentgen-ray plates, exposures shortly ranged from a few seconds for a hand to thirty to sixty seconds for heavy parts of the human body (April, 1896).

What was then thought to be the proper characteristics of a roentgen-ray emulsion, may be summed up in Mr. Carbutt's words (June, 1897):

> It should be of medium sensitiveness, have a good body of emulsion, be capable of absorbing the x-rays thereby giving more detail and perspective to the bones.

A few years later, Dr. Eugene W. Caldwell seemed to obtain best results on plates of medium or fast photographic speed such as "Hammer Extra Fast," "Cramer Banner," "Seed's 26 X or 27." Double emulsion coated plates (one side) which were obtainable as non-halation plates offered some advantage. The "Hammer Aurora" was found to give excellent results where it was desirable to use a double emulsion coated plate because of lessened exposure.

Celluloid films were not so desirable because of their tendency to curl, but they had this advantage—they could be placed between two intensifying screens with a consequent reduction in exposure. In Germany this type of film was made for roentgen-ray work about 1896–1897 by the Schleussner Company, such film having a double emulsion coat on each side, making four coats in all. This company also made roentgen-ray plate and was probably the only company in those days making an emulsion which approached the density, contrast and speed suitable for roentgen work. The finest roentgenograms seemed to be made on their films but due to their high cost they were not very popular.

Roentgen-ray plates when first supplied, (1896) were inserted in light-proof wrappers and sealed, but it was found that the plates deteriorated through the unavoidable chemical interaction between the paper and emulsion. The envelopes were later furnished separately and the operator "loaded" his own plates as needed.

PAPER ROENTGENOGRAMS

The quest for a more satisfactory sensitive material for roentgen-ray purposes led many workers to experiment with bromide papers. The first sensitized paper, prepared especially for roentgen-ray purposes, was announced by the Eastman Kodak Company in 1901. The sensitivity of this paper was less than that of glass plates. Interpretations from paper roentgenograms were more difficult to make for the photographic scale of gradation of a roentgenographic image recorded on paper and viewed by reflected light was much shorter than that of an image recorded on a transparent base, such as a plate, when viewed by transmitted light. Consequently, fine detail so essential in roentgenography, was difficult to record. Other shortcomings soon led to the abandonment of such sensitized paper for roentgenography. Several attempts have since been made by other manufacturers to introduce a sensitized paper for roentgenographic purposes but their efforts have not met with success.

EARLY PHOTOGRAPHIC PROBLEMS

The successful pioneer roentgenologist practised photography, invariably as a hobby, and the production of excellent quality roentgenograms of those days was dependent primarily upon the roentgen worker's photographic knowledge. All of the manipulative measures of the photographer were used.

In those days, the plate, after exposure, was developed to produce a photographic print on sensitized paper rather than a roentgenographic negative. Today we know that direct interpretation of those plates was almost impossible. Prints were required and all interpretations were made therefrom. The early roentgen-ray plate possessed wide latitude with little contrast, and only high quality, distinctive results could be produced in the prints.

The photographic journals were the media for discussion of the roentgen rays in 1895–1896. In fact roentgenography was considered as a new specialty in the field of photography. In scanning these journals, items and articles concerning x-rays progressively diminish, so much so that from 1897 on, little if anything of interest appears. This was undoubtedly due to the increasing prominence of the various medical roentgen-ray journals, which naturally effaced the influence the photographic journal had in the days of 1895 and 1896, and "roentgen photography" soon assumed the dignity of the medical specialty, roentgenology.

Considering the photographic aspect of

the roentgenogram as described in the photographic journals of the days immediately following Roentgen's discovery, it is interesting to note that most of the workers who were actively engaged in making roentgenograms were photographers, or physicians who practised photography as a hobby. "Roentgen studios," conducted by photographers sprang up in America and Europe advertising the fact that they were conducting a business in "Roentgen photography" and that appointments could be made for "x-ray sittings."

The competitive spirit soon began to be manifested and it is amusing to read what the *Photogram* of June, 1896, records:

> Radiographic studios appear to be opening everywhere. One of the latest is at the London Stereoscopic Company's premises in Regent Street. Jones & Scott of Exeter, have fitted themselves very completely, . . . for all classes of surgical work. Unfortunately, some of those who have gone into the line are already working at ridiculous prices—an original surgical radiogram for half a crown (*about 65 cents*), for instance—but our own experience of the uncertainty of the subject, and the skill necessary to ensure any regular success, makes us think that these people will not long keep to such prices, or anything approaching them.

Naturally the medical profession was canvassed and the majority of the work done by these studios was essentially medical or surgical in character. Occasionally curious persons requested roentgenograms of various opaque objects such as pieces of sculpture, jewelry, pearls, diamonds, metal castings, mummies and other objects of like nature.

Because these early roentgen-ray workers followed the photographic procedure as practised by the professional photographer, they made roentgenograms which would give them good prints, and they were usually made on a popular brand of Velox paper which had considerable contrast. Because of the high degree of contrast which exists in the present type of roentgen film, it is quite difficult to make satisfactory reproductions for publication except by the intermediate "positive" method. It is also known that to secure as perfect a reproduction as possible, and at the same time, show the bony areas light, and the soft tissues, dark as in the original, the roentgenogram should not have the high degree of contrast which is normally obtained in the modern roentgen laboratory. Intermediate copies of the roentgenogram must be obtained in which the maximum amount of detail is observable yet with little contrast. This type of negative is commonly called "soft" by photographers—one having a long scale of gradation. The desired contrast is built up in the print or lantern slide so as to match the original roentgenographic negative.

In the early development of roentgenograms and prints, the roentgenographer "developed" by means of the old "four bottle" photographic method, covering his sensitive material first with a solution containing the developing agent, preservative and accelerator, then the bromide. As development proceeded he added a little of the solution from one or another of the bottles containing the essential components as his judgment dictated, until development was completed. The roentgenographer or photographer thought that thereby he was able to bring out the anatomical detail desired. The manipulation of bottles was after all a futile effort for the process tended to mislead, for the reason that after exposure the roentgenographic image could not then, nor at this day, be changed in any marked degree by quantitating the developing components. The most prevalent method of increasing the density of the image was through after-treatment (intensification) of the negatives and many of the leading roentgen workers of that time resorted to that practice.

The difficulties of development were problems that necessitated ingenuity and intelligence to overcome. Quoting the experiences of Dr. E. R. Corson of Savannah, in one of his early papers, we read:

> In my earlier x-ray work I intrusted the developing and printing of the plates to a professional photographer; but I soon found that,

unless I had him entirely at my beck and call it was impossible to do any systematic work. There were certain differences in photographic technique to produce prints from negatives, such, at any rate, as I conceived they should be, that he had much to learn, just as I had to learn the entire process, having had no previous knowledge or experience in photographic work. I found that what the professional would regard as a fine negative did not always give a satisfactory print, one that gave the deep and essential details without the superficial ones and the flesh. Thus I found that every negative had to be intensified just as regularly as the plate was developed and fixed. There were further difficulties to be overcome in printing which did not exist in ordinary photographic work. This is not the place to give the details of this work, and I shall describe them in a separate paper. . . . I have used the Carbutt x-ray plates as well as the Seed's extra-rapid plate, No. 27. This latter plate is cheaper and just as good as the Carbutt, and I use it now entirely. I have found that the Eastman hydrochinon developing powders are as good as, perhaps better than, any other developer, and very handy. I use a chrome-alum fixing bath as given by Carbutt and Carbutt's formula for the intensifier. For a printing paper I use solely the "Carbon matt Velox," which has many advantages over all other printing papers, at least to produce prints as I conceive they should be.

The average photographer usually had no conception of what the roentgenologist expected in the roentgenogram of those days. Even today the average photographer does not always develop a roentgenogram satisfactorily for he is unaware of the photographic quality desired by the roentgenologist.

The demand created for roentgen-ray plates soon led to the manufacture of many brands such as the Paragon X-ray Plate; Forbes X-ray Plate; Cramer X-ray Plate; Central X-ray Plate; Universal X-ray Plate; Diagnostic X-ray Plate; and, many others in England, France and Germany.

This demand for better roentgen-ray materials shortly became so insistent that it was only natural that the Eastman Kodak Company should also become interested in their manufacture. So in 1912 the first Kodak x-ray plate was manufactured. This was the Wratten X-ray Plate, coated with a heavy silver emulsion which was impregnated with a bismuth salt, the purpose of which was to stop the roentgen-rays and increase the effect on the silver halide grains in the emulsion.

The Seed Dry Plate Company soon offered the Seed X-ray Plate to the profession. These plates were well received and were in popular favor for many years until the advent of roentgen film.

Prior to the World War in 1914, the glass used for photographic plates was secured from Belgium. The German warfare on Allied shipping and the invasion of Belgium soon curtailed this source and the procuring of glass for photographic purposes soon became a very serious problem.

The demands of the Armies for roentgen plates in their hospital x-ray laboratories became so great that it was almost impossible to satisfy them. Even if glass plates were available in large quantities, their bulk and fragility made them exceedingly difficult to transport without breakage. The demands finally made it incumbent upon the Kodak Company as one of the larger producers of x-ray plates to find some other support than glass for the emulsion.

Roentgen work required sensitive surfaces of large area. The base upon which the emulsion was to be coated had to have sufficient body to support the weight of the heavy x-ray emulsion without buckling to any large degree. It also had to be glass-clear. The only thing to be done was to adapt the cellulose nitrate base used in the manufacture of photographic film. Hence, in 1914, the single-coated roentgen film was manufactured with an emulsion of greater sensitivity than that on any roentgen plate made theretofore. However, even this type of film was not ideal. It curled excessively and was very difficult to develop in trays. It seemed at that time that some kind of frame to hold the film during development was needed. Many roentgen laboratories did use tank development, but in

the aggregate, there were relatively few.

The urgency of war demanded greater efficiency and speed in the x-ray film because of its use with portable x-ray apparatus in the field. This need brought to a head the extensive research work then being conducted on a double-coated film which made possible double-screen technique. So, in 1918, a modern "duplitized" x-ray film was made available. The enormous increase in speed accentuated by double screen technique, and the facility for handling by means of the new film hanger just introduced, seemed to be the utmost in convenience for the roentgenologist, yet, improvements were steadily being made until finally in 1919, "dupli-tized" film was as near perfect as the manufacturer could make it. X-ray plates were then slowly giving way to the new recording medium until today every roentgenologist uses film.

Before leaving the subject of plates it is interesting to note that as late as 1918, a calcium tungstate plate was suggested by Dr. Max Levy and manufactured by the Imperial Dry Plate Company in England. This plate consisted of a glass support coated with emulsion on one side over which was placed a coat of calcium tungstate crystals. After exposure and before development the plate was held under the tap water to wash off the screen coating. The plate was then developed in the ordinary manner. These plates were expensive to manufacture, showed considerable grain and were somewhat impractical.

The introduction of film was no easy task. There were years and years of prejudice to overcome. Roentgen-ray workers had so accustomed themselves to glass plates that it was a hard job to convince them that film held forth any advantages over the plate. However, its advantages soon became evident to all, and today no roentgenologist would ever revert to the practice of using plates.

The year 1923 brought to the roentgenologist a faster x-ray film whose sensitiveness was the greatest ever placed at the disposal of the roentgenologist. It effected a radical shortening of exposure time as well as kilovoltage, consequently less wear and tear on tubes and apparatus. The base of this film as well as its predecessors consisted of cellulose nitrate.

Cellulose nitrate as a film base, however, presented a fire hazard which hospitals and laboratories were forced to recognize because of several fires caused by careless handling and storage of such film. Experimentation with a slow-burning film base finally reached a point where the manufacturers felt that they could conscientiously offer a safety base of cellulose-acetate. They were of the opinion that this base could be of better quality but the exigencies of the fire problem were so acute that the demands for a safety film had to be satisfied even though the product was not all that could be desired. Safety film was then placed on the market in 1924. Cellulose acetate has and perhaps always will be, a difficult substance to produce in large quantities. Its purity must be unquestioned otherwise defects arise in the emulsion. Experimentation still was carried on in a most extensive manner and each lot of safety film manufactured was gradually improved.

The introduction of a contrast film in 1925 was a new departure in film manufacture. This film possessed a high degree of contrast and yet retained all of the sensitiveness to roentgen rays characteristic of its predecessor. This type of film seemed to fill the need of the roentgenologists, for besides its inherent characteristics it could also be had on safety base. The difficulties in manufacturing safety film had by this time been almost mastered.

Progress cannot mark time and in 1930, a film made with a light diffusing characteristic and a decided increase in sensitiveness was produced followed by a clear base film of the same sensitiveness. Both emulsions were procurable on nitrate or acetate base of equal clearness.

DENTAL FILMS AND PLATES

Perhaps the first recognized dental roentgenogram on record was made two weeks

after the announcement of the discovery of the x-rays by Dr. Otto Walkhoff of Braunschweig, Germany. This roentgenogram was made of Dr. Walkhoff's own teeth with an exposure of twenty-five minutes using an ordinary photographic plate cut to a small size and wrapped in black paper and covered with rubber-dam.

Mr. Frank Harrison, an Englishman, first published an article describing the method of making dental roentgenograms on film in the *Journal of the British Dental Association*, September, 1896. Dr. W. J. Morton of New York was the first in America to make a dental film roentgenogram prior to April, 1896.

The results of these early roentgenograms were rather crude and of no diagnostic value, but it brought to the attention of the dental profession the fact that here was an invaluable diagnostic adjunct to their practice. The element of doubt regarding the roots of teeth and character of the jaws was immediately eliminated for one of exact knowledge.

Owing to the small difference between the density of bone and tooth it was necessary to have a roentgenogram of full contrast. Much of the early dental roentgenography was done on photographic plates, films and bromide papers. However, following the lead of the late C. Edmund Kells, Jr., D.D.S., of New Orleans, La., many preferred to use films.

While glass plates proved satisfactory for the anterior region of the mouth where the curved surfaces did not cause undue distortion because of the flatness of the plates, yet in the posterior region, the flat surface of the plate caused some distortion. We know now that this was entirely a matter of improper tube angulation. Soon film was used extensively and Kodak roll and Seed's double and triple emulsion coated films became favorites.

Shortly after the discovery of x-rays, the uses advanced for dental roentgenograms did not differ in any great degree from those now employed in the periapical roentgen examination. Even in dental roentgenography prior to 1901, film presented many advantages. Its thinness and flexibility as compared to plates provided a means whereby a small packet could be placed conveniently in the mouth. Of course the problem of distortion was a great one, yet when observation had to be made of so small an object as a single tooth, a certain amount of care in arranging the position of the patient and tube helped to overcome this difficulty. In dental roentgenography there was no very great difficulty in securing good density; the depth of tissue to be penetrated was so small that very little distortion took place, hence the definition was usually good and there was little tendency on the part of the film to fog.

The need for a specially wrapped packet containing dental films was an important one. Various wrappers were used, the most successful being black and orange paper and black dental rubber then used as dams. Dr. Kells was probably the first to suggest and use two dental films in a packet so as to have a duplicate in case one was lost or sent to a referring physician. Kodak roll film was extensively used in this country and in England because of its flexibility and ease with which it could be handled in the darkroom. The exposure in those early days varied from twenty to ninety seconds.

In 1913 a red, waxed, moisture-proof, hand-wrapped paper packet in which were two single-coated dental films enclosed in a black wrapper was introduced. Various emulsion speeds were employed and the films were cut in the sizes as used today. These films were in constant use until superseded by the present machine-made packets which facilitate placement in the mouth, and are more comfortable to the patient. Many styles of packets have since been employed by many manufacturers but the most convenient seems to be one made of moisture-proof paper. In 1925, the first double-coated "radia-tized" dental film with a very fine grained emulsion was manufactured in a neatly designed machine-made packet. This type of film rendered greater contrast between the tissues of the teeth and bone with consequently greater detail.

Various sizes to permit roentgenography of children's teeth, the dental arch and impacted teeth were soon developed, the most recent development being the bite-wing dental film to determine the presence of interproximal cavities. The neatly prepared and sanitary dental film packet of today is a far cry from the first pieces of crudely wrapped photographic plates. The modern dental film packet has firmly established itself in modern roentgenography.

This narrative of the outstanding efforts in the evolution of x-ray plates and films is but a small part of the complete story. The accompanying development of apparatus, intensifying screens, tubes, chemistry of processing, all contributed a great deal in shaping the character of acceptable x-ray film. Only a few final remarks can be made in bringing to a close this most interesting subject.

One is so often asked what are the relative differences in speed between the early x-ray plates and the present ultra-speed film. It is impossible to make any attempt at accurate comparisons as to the relative speed of plates and films of the late nineties and those of today. The reason for this is that in those early days, photographic sensitive materials were made which would only occasionally be considered quite satisfactory in speed now, but these were more or less accidents; and the lack of *uniformity of those plates or films was very evident.*

Frankly, the lack of uniformity in the early days was not a matter of great concern. The unstable characteristics of tubes and apparatus tended to make each roentgenogram a distinct problem. Today, however, with standardized technique, fairly reliable tubes and accurate roentgen apparatus, *uniformity* in the roentgen film is an absolute necessity. Therefore, the importance of uniformity is paramount to the manufacturer of highly sensitive roentgen film, and great pains are taken in overcoming the difficulties in maintaining this uniformity. The advance that has been made in emulsion making is not so much evidenced by an increase in the maximum speed obtainable as by an ability to maintain high speed with *regularity*.

The development of x-ray plates to the present efficient x-ray film is significant, for it depended upon one of the most important elements in the successful manufacture of highest quality products—industrial research. This research permits the inherent characteristics of x-ray film or of any other goods to be maintained uniformly constant. The consumer is then sure that his x-ray film or whatever other high grade materials he uses, will be standard.

Industrial research means *experimentation;* and the foundation for positive knowledge which is so necessary to the industrial investigator, lies in specialized facts—*accumulated through experimentation*. Taken in the aggregate, properly classified, and interpreted, these *facts* lead to discoveries, and these discoveries in turn develop knowledge. Thus knowledge does not evolve from a single mind working independently, but from the cumulative efforts of many minds.

Research investigators are organized and trained to work together in this way toward knowledge. They are chosen because of their thoroughly painstaking logical methods. They do not, as individuals, scatter their energies over too broad a field of effort. Each one specializes, and each cooperates with all the others.

What originally was a discovery in molecular physics has today become the science of roentgenology; concomitantly another science has arisen whose reason for existence is based upon the production of x-ray film so necessary to the proper functioning of its sister science.

The remarkable part photography has played in roentgenology can never all be told. The men who labored so assiduously, experimenting and making new discoveries in x-ray emulsion-making were the silent soldiers standing behind and jealously guarding the marvelous internal growth of roentgenology.

Let us hope that as the years go by *experimenting* will continue and unfolding from its results will arise a roentgen-ray sensitive medium which will be the *ideal* of roentgenologists.

Vol. XXVI, No. 4

EARLY AMERICAN ROENTGENIANA*

By EDWARD H. SKINNER, M.D.
KANSAS CITY, MISSOURI

THROUGH fortuitous circumstance rather than through the eager search of a collector, nearly all of the books and journals pertaining to the development of the roentgen ray in America are now installed at the Library of the Jackson County Medical Society at Kansas City. Of course these are only the historical background of a rather complete library of the roentgen literature of the world, including complete files of the roentgen journals of all countries except the Italian.

The earliest announcements in America of the discovery of the x-ray were in newspapers and these continued to play up this new agent for many a year. I do not possess any of these items. They are available in the bound files of many libraries but have never interested me because of their inaccuracies and wild exaggerations.

The files of the *Electrical Review* carry the history of the studies of physicists in various articles and notes and offer the best record of the serious efforts of capable men to develop a true appreciation of the qualities and production of the x-ray.

Before Roentgen's announcements were one year old there were three small books published in America, two of which are noted here.

1. Roentgen Rays and the Phenomena of the Anode and Cathode. By Edward P. Thompson, M.E., E.E., author of "Inventing as a Science and an Art." Concluding chapter by Professor A. Anthony, with sixty diagrams and forty-five half tones. 8vo., cloth. Price, $1.50.

This book is extraordinarily complete and is written in numbered paragraph style. There are 210 paragraphs with cross references and a good index. It is interesting to note that the word anode was spelled "ariode" in the title of a review in the *American X-Ray Journal*. This error is continued in various reviews and references to this book in succeeding literature. I can find only very little about the author but he seems to have been one to take advantage of the demand of the day for some collection of source material.

2. The X-Ray, or Photography of the Invisible. By William J. Morton, M.D., in collaboration with Edwin W. Hammer. New York: American Technical Book Company. 196 pages, 57 illustrations, forty half tone roentgen plates. Copyright 1896. Preface date, September first, 1896. Price $.75.

This book, produced in collaboration with Edwin W. Hammer, an electrical engineer, seems to have been promoted by the publishers for popular consumption. But it is quite remarkable and carries some really excellent half tone plates which do not seem to have been retouched. There are three appendices: (1) The translation of Roentgen's first article; (2) the experiments of Thomas A. Edison, signed by himself; (3) Sir Oliver Lodge's hypothesis upon roentgen rays. All of these are valuable as source material. Morton's conclusions at this early date (September 1, 1896) are worthy of quotation:

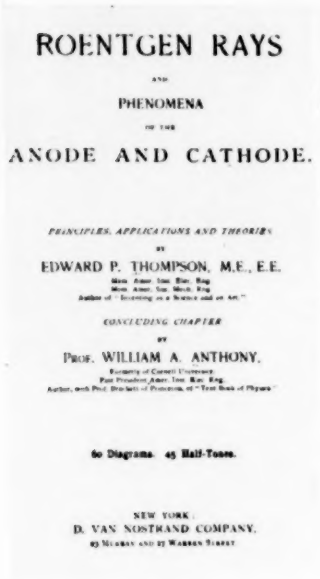
"It is difficult to say to what final uses the simple fact discovered by Roentgen that different substances are more or less opaque to the X Ray, according to their density, may be put. We have laid stress mainly upon its uses in surgery but there are several other applications of great interest. . . . Flaws and weldings may be discovered in metals; investigation as to the amount of metal in different ores may be made, and it will interest dealers in diamonds to know that the X Ray positively distinguishes between the true diamond and the paste imitation. . . . Not only can handwriting in sealed envelopes be photographed by the aid of the X Ray as in Fig. 91 (which purports to be a man's will sealed in an envelope as an experiment) but in a negative not here produced an X Ray photograph of handwriting inside the plate holder was taken even after the X Ray has passed through a human skull. In reading these pages up to this point one can hardly fail to be impressed with the wonderful results already achieved in this most attractive field of investigation as well as with the enormous possibilities lying dormant in Prof. Roentgen's discovery.

* Presented at the Thirty-first Annual Meeting, American Roentgen Ray Society, West Baden, Ind., Sept. 23–26, 1930.

Positive statements as to why and how are as yet out of place; almost every hour brings with it new theories and new developments, and we can confidently look forward to more definite results and knowledge in the near future."

3. Another interesting early book is "The A.B.C. of the X-Rays," by William H. Meadowcroft. New York: American Technical Book Company. Price $.75. Meadowcroft was with Edison. Dr. P. M. Hickey quotes a letter from this author in 1928 where he still signs himself as assistant to Mr. Edison.

In 1897 appeared a "Manual of Static Electricity in X-Ray and Therapeutic Uses," by Dr. S. H. Monell of Brooklyn which has been catalogued as follows:


ROENTGEN RAYS

AND

PHENOMENA

OF THE

ANODE AND CATHODE.

PRINCIPLES, APPLICATIONS AND THEORIES

BY

EDWARD P. THOMPSON, M.E., E.E.

CONCLUDING CHAPTER

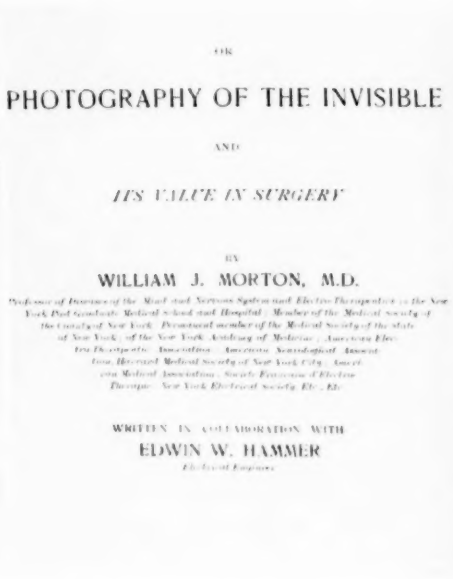
BY

PROF. WILLIAM A. ANTHONY,

60 Diagrams. 45 Half-Tones.

NEW YORK:
D. VAN NOSTRAND COMPANY.

Fig. 1.


OR

PHOTOGRAPHY OF THE INVISIBLE

AND

ITS VALUE IN SURGERY

BY

WILLIAM J. MORTON, M.D.

WRITTEN IN COLLABORATION WITH

EDWIN W. HAMMER

Fig. 2.

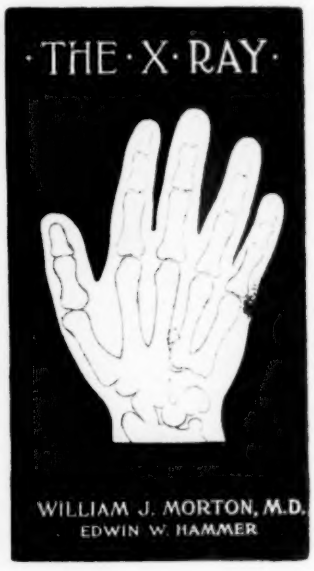


Fig. 3.

Die Röntgenstrahlen

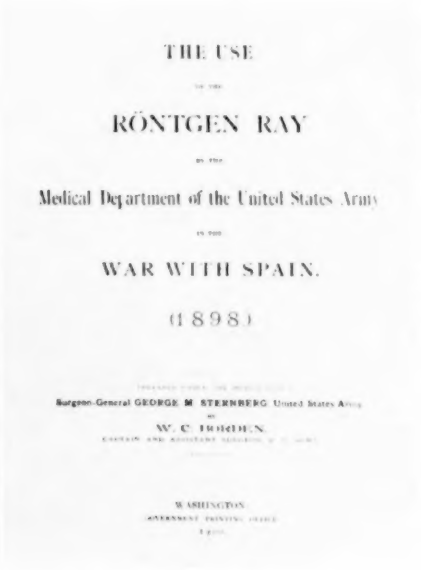
n Dienste der Chirurgie.

Von

Dr. Carl Beck,
Professor der Chirurgie,
New York.

München 1902.
Verlagsbuchhandlung Lehmann & Schauer

Fig. 4.


THE USE

OF THE

RÖNTGEN RAY

IN THE

Medical Department of the United States Army

IN THE

WAR WITH SPAIN.

(1898)

Fig. 5.

THE ROENTGEN RAYS

IN MEDICINE AND SURGERY

AS AN AID IN DIAGNOSIS AND AS A THERAPEUTIC AGENT

FRANCIS H. WILLIAMS, M.D. (Harv.)

New York
THE MACMILLAN COMPANY

Fig. 6.

Manual of Static Electricity in X-ray and Therapeutic Uses. By S. H. Monell, M.D., Founder and Chief Instructor of the Brooklyn Post-Graduate School of Clinical Electro-Therapeutics and Roentgen Photography: Fellow of the New York Academy of Medicine; Member of the New York County Medical Society: Kings County Medical Society: Editor of the Electro-Therapeutic Department of the Medical Times and Register: Author of the Treatment of Diseases by Electric Currents. A Hand Book of Plain Instruction for the General Practitioner, Etc. Second edition. William Beverly Harrison, N.Y. 670 pages. Octavo, cloth, gilt. Price, $6.00 net.

PREFACE

In these notes are recorded some impressions derived from experiments made after the day's work, as a recreation, yet with the hope of learning to design and construct apparatus for my friend, Dr. F. H. Williams, who has done most to show the importance of X-light in medical diagnosis.

WILLIAM ROLLINS.

Fig. 7.

This is not a very satisfactory book. It is saturated with high-frequency currents and impossible therapeutic advice and promises. The x-ray portions are paraphrased lifts. It needs no further comment.

Die Röntgenstrahlen im Dienste der Chirurgie. Von Dr. Carl Beck, Professor der Chirurgie, New York. München 1902. Verlagsbuchhandlung Seitz & Schauer.

Roentgen Ray Diagnosis and Therapy. By Carl Beck, M.D. Professor of Surgery in the New York Post-Graduate Medical School and Hospital; visiting Surgeon to St. Mark's Hospital and the German Poliklinik. With 322 illustrations in the text. New York and London. D. Appleton and Company. Price $4.00.

These two books deserve to be included in our listing because they are serious efforts to record roentgen-ray values. Beck had published a two volume text under similar title in German a short time before. Beck is generally conceded to have been the first to furnish a roentgenogram of opaque gallstones with operative proof.

Following the Spanish-American War, the War Department published a report by the Surgeon-General entitled:

The Use of the Roentgen Ray by the Medical Department of the United States Army in the War with Spain. (1898.) Prepared under the direction of Surgeon-General George M. Sternberg, United States Army. By W. C. Borden, Captain and Assistant Surgeon, United States Army. Washington: Government Printing Office, 1900.

We now come to the three most valuable books by American authors published during the first decade of roentgenology. They have served as excellent guides and are really the foundations of American roentgenology. During all these years the journals carried articles by these authors; not the x-ray journals but the better general and special journals of America such as the *Boston Medical and Surgical Journal*, the *American Journal of Medical Sciences*, the *Journal of the American Medical Association*, and others.

These three books are:

1. The Roentgen Rays in Medicine and Surgery. As an aid in Diagnosis and as a Therapeutic Agent. Designed for the Use of Practitioners and Students by Francis H. Williams, M.D. (Harv.) Graduate of the Massachusetts Institute of Technology; Visiting physician of the Boston City Hospital: Fellow of the Massachusetts Medical Society: Member of the Association of American Physicians: Member of the American Climatological Association: Fellow of the American Association for the Advancement of Science: Fellow of the American Academy of Arts and Science, etc. With 428 illustrations. Third edition. With enlarged appendix. New York. The Macmillan Company. London: Macmillan and Company, Ltd. 1903. All rights reserved.

2. The Practical Application of the Roentgen Rays in Therapeutics and Diagnosis. By William Allen Pusey, A.M., M.D. Professor of Dermatology in the University of Illinois: Member of the American Dermatological Association, and Eugene Wilson Caldwell, B.S. Director of the Edward N. Gibbs X-Ray Laboratory, University and Bellevue Hospital Medical College, New York: Member of the Roentgen Society of London: Associate Member of the American

Institute of Electrical Engineers. Second Edition thoroughly revised and enlarged. Philadelphia, New York, London. W. B. Saunders & Company, 1904.

3. Notes on X-Light. By William Rollins. Boston, Massachusetts. 1904.

In 1904 there also appeared a very good volume by Drs. Charles Warrenne Allen, Milton Franklin and Samuel Stern upon Radiotherapy with this title page:

Radiotherapy and Phototherapy including Radium and High-Frequency Currents. Their Medical and Surgical Applications in Diagnosis and Treatment. For students and practitioners. By Charles Warrenne Allen, M.D. Professor of Dermatology in the New York Post-Graduate Medical School; Consulting Dermatologist to the Randall's Island Hospitals; Consulting Genito-Urinary Surgeon to the City Hospital; Member of the American Medical Association;

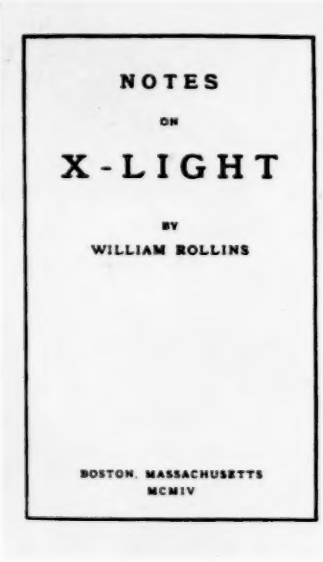

NOTES
ON
X-LIGHT
BY
WILLIAM ROLLINS
BOSTON, MASSACHUSETTS
MCMIV

Fig. 8.

RADIOTHERAPY AND PHOTOTHERAPY.
RADIUM AND HIGH-FREQUENCY CURRENTS.
THEIR MEDICAL AND SURGICAL APPLICATIONS IN DIAGNOSIS AND TREATMENT.
FOR STUDENTS AND PRACTITIONERS.
BY
CHARLES WARRENNE ALLEN, M.D.
MILTON FRANKLIN, M.D.
AND
SAMUEL STERN, M.D.
ILLUSTRATED WITH 131 ENGRAVINGS AND 27 PLATES IN COLORS AND MONOCHROME
LEA BROTHERS & CO.
NEW YORK AND PHILADELPHIA.

Fig. 9.

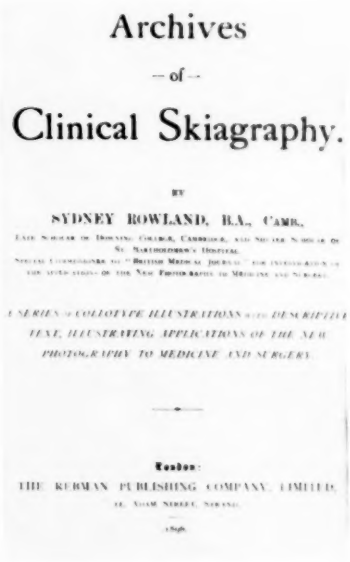

Archives
— of —
Clinical Skiagraphy.
BY
SYDNEY ROWLAND, B.A., Camb.
London:
THE KEMKAN PUBLISHING COMPANY, LIMITED.

Fig. 10.

Fortschritte
auf dem Gebiete der
Röntgenstrahlen
Hamburg

Fig. 11.

AMERICAN ELECTRO-THERAPEUTIC
AND X-RAY ERA
PUBLISHED MONTHLY

Fig. 12.

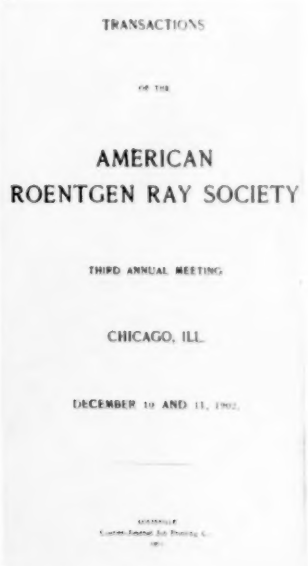

TRANSACTIONS
OF THE
AMERICAN
ROENTGEN RAY SOCIETY
THIRD ANNUAL MEETING
CHICAGO, ILL.
DECEMBER 10 AND 11, 1902.

Fig. 13.

The American Dermatological Association; The New York Dermatological Society, etc. With the co-operation of Milton Franklin, M.D. Lecturer on Electro-Radiotherapy, New York Polyclinic Medical School and Samuel Stern, M.D. Radiotherapist to Dr. Lustgarten's Clinic at the Mount Sinai Hospital; Clinical Assistant to the Skin Department of the New York Post-Graduate Medical School. Illustrated with 131 engravings and 27 plates in colors and monochrome. Lea Brothers and Company. New York and Philadelphia. 1904.

This is a very good book and presents protection and filtered roentgen therapy in a manner most advanced for its day. The book seems to have made little impression as good as it is. The chapters upon skiagraphy are brief but quite correct. There is a long chapter upon x-ray burns and upon other deleterious actions of the x-ray. It seems to be the first attempt in American roentgen literature to present the English and Continental viewpoints and to cite their literature and illustrate their apparatus. It is really a pity that this book did not enjoy a better distribution for it certainly would have been an excellent influence for better radiotherapy. Probably the Pusey-Caldwell volume overshadowed Allen's at the time, because Caldwell's portion was quite advanced and thoroughly done. Salesmanship and more efficient advertising probably had a great deal to do with this situation.

The Williams book will remain a classic in roentgen literature. Williams had contributed to journal literature from 1896 and it remained for him to collect these and the additional roentgen observations of a clinical practitioner into a handsome volume. Probably no roentgen book has enjoyed wider or more appreciative distribution. Succeeding reprintings and editions were demanded. Its contents are worthy of a deliberate analysis not to be exercised in the time that I am devoting to ten years of American roentgen literature.

Pusey and Caldwell evidently wrote individual portions of their book without consultation. One may surmise that the publisher picked the two best men in America to do exactly what they did—produce a best-seller with merit based upon technical knowledge, sagacious observation and extensive experience. There is no need for me to extol this volume for the fame of the authors is sufficient. Caldwell has passed to his reward, with the Caldwell lecture as the perpetuating yearly bloom to his memory. Pusey has been a leader of our profession and remains to charm us with his autumnal philosophy and guide us with observing wisdom.

Since constructing this article the following letter has been received from Dr. Pusey, dated September 17, 1930:

My dear Dr. Skinner:

It was a pleasant surprise to have you write and ask me the questions about Caldwell's and my book. It revived pleasant memories of a delightful association. The history of it, I should say, is about this:

In the summer of 1903 I had gotten overwhelmed in therapeutic X-ray work, which I had begun in a small way in 1900. I had gradually become impressed with the great possibilities of X-rays in therapeutics, partly from my clinical experience and others' reports, but especially from the therapeutic indications that seemed to me to exist, partly as a result of my own deductions and partly on the basis of the generalizations of Freund of Vienna concerning the therapeutic indications of X-rays. As soon as I demonstrated cases showing its remarkable effects in acne, in lupus and, especially, in epithelioma, the cases rolled in and, by the summer of 1902, I had so much material that I had a book in mind. Since my very first reports many doctors had been coming in to see the work. At this time, early in the fall of 1902, Caldwell came in to see me. I found at once that he was a finished physicist in the field of electricity and X-rays. I saw quite a little of him for a day or two. I may have proposed writing a book together, he doing the physics and diagnostic side of it and I doing the therapeutic side, but I think the proposition came from him. At any rate we immediately began to go ahead with it. I had never met Caldwell before; in fact, I do not think I had ever heard of him, because I had no interest in the diagnostic side; but nobody could meet Caldwell without being

impressed with his patent honesty and with his great knowledge in his field. You asked about ideals. I remember Caldwell saying that his ideal was to write the last word for the time in his field. The purpose that I had in mind was simply to report my experience and make an exposition of the subject as it had developed in my own mind. There was no literature, that I had seen, at the time that covered the field that I was traversing, so that I could carry out my own plans. That sounds hard but it was really easier, because after I got into the clinical side of the subject I was writing nearly altogether out of my own experience and did not have the terrible burden of great literature to be reviewed.

One more word about Caldwell: Caldwell shortly after that began to have serious trouble with his hands. That interfered with his living up to his ideal of keeping the book constantly at the front. By the time we had gotten out a second edition he was in so much trouble that work on further editions was impossible.

As far as I was concerned my part of the book was a personal book. It was a report of personal experiences and there was no particular use for further editions, so that when Caldwell broke down I never considered going further with it.

I saw Caldwell occasionally during the several years that he lived. He went through that old experience of fighting X-ray hands, with one mutilating operation after another until the thing finally got him. He was the best trained pioneer in his field, the soundest and the most interested that I met, and I have never felt that he got all the credit he deserved. I am glad that you are going to say something about him.

I appreciate what you say about the book. Frankly I have always had some pride in my part of it, especially in the fact that I was not carried away by the subject and put nothing in it that the subsequent 27 years of therapeutic X-ray experience of the world in general has given me any embarrassment to defend. As a matter of fact about all the therapeutic uses of X-rays, I believe, were either reported in the book or foreshadowed.

Cordially yours,
(Signed) Wm. Allen Pusey

And now to Rollins: Here is a vade mecum for past and future roentgen engineers. How Williams must have loved this silent sort of physicist who could translate a wish into apparatus! This book must have had an extremely limited printing and distribution. My volume is still fresh and yet I secured it years after the printing. When I look through its pages I see all of the latest models in x-ray tables; I see the developments of the future and the failures of the past; the dreams of the enthusiast and the nightmares of the roentgen neophyte. Rollins published this book in 1904, yet I see the original inventions of many roentgenologists since that date, quite well illustrated.

Although I have given only a cursory review of the books of the first American roentgen decade, I must consider the essential roentgen journals and the general journalistic distribution of roentgen articles of this period. But these will be brief since most of the valuable contributions with the exception of those of Leonard, are collected or quoted in the books of Williams, Allen, Pusey and Caldwell, Kassabian (1907) and Rollins, and because these early American roentgen-ray journals, while interesting, were inclined somewhat toward commercialism, and comparison with the early English and German roentgen literature is unpleasant. The earliest English roentgen journal—*The Archives of Clinical Skiagraphy*—possessed a charming and satisfactory dignity although served by the same press dispatches as America. The first issue was in May, 1896. The first issue of the German publication—*Fortschritte auf dem Gebiete der Röntgenstrahlen*—was published at Hamburg in September, 1897.

The original *American X-ray Journal* was produced in May, 1897, by Dr. Heber Robarts in St. Louis. It continued until Volume 19, No. 6, 1906. Robarts died May 1, 1922, at Belleville, Illinois near St. Louis. The organization meeting of the Roentgen Society of the United States was in Dr. Robarts office in March 26, 1900, having been called through the efforts of Dr. Rudis-Jicinsky of Cedar Rapids, Iowa. Robarts was elected president and Rudis-Jicinsky secretary. The first annual meeting was held in the club rooms of the Grand Central Palace in New York, December 13 and 14, 1900. Robarts continued this jour-

nal to Volume 19 in 1906 when it was combined with the *American Electro-Therapeutic and X-Ray Era* to form the *American Journal of Progressive Therapeutics*.

In 1900 the *Electro-Therapeutic and X-Ray Era* was printed under Friedlander and Burdick at Chicago. The second issue became the *American Electro-Therapeutic and X-Ray Era*. It continued to Volume 4, 1904. This small publication had a checkered career. It was violently commercial. Its pages record bickerings between members of the Chicago Society of Electrotherapeutists, which was its background.

These early journals are nothing to look back upon with reverence or with any ideas of a hallowed past. The printing is poor and the pages are not attractive. The advertisements are peculiar, to say the least. The first issue of the *Transactions of the American Roentgen Ray Society* was in 1903 and is a splendid dignified volume. It continued until 1908, or for six volumes.

Then came the *American Quarterly of Roentgenology*, with Dr. P. M. Hickey as editor, with the first issue in October, 1906, which has developed into the *American Journal of Roentgenology and Radium Therapy* with which we are familiar today.

"The First Decade of American Roentgenology" has been described by P. M. Hickey in the August and September issues of the *American Journal of Roentgenology and Radium Therapy*, 1928. This excels in its recital of the leading roentgenologists of the first decade, is excellently written and the authenticity of its contents has been proved. The author was intimately acquainted with the men and events of this period. I have attempted not to trespass upon the premises of this excellent article.

Again, A. C. Christie contributed a historical sketch of "Roentgenology in North America" in *Acta radiologica*, 1926, *6*, 281–293. Christie's article is rather brief and therefore his choice of pioneers is limited. But there is no doubt of the correctness when he chooses to eulogize Williams, Leonard and Caldwell and to praise Snook, Coolidge and Potter.

A REVIEW OF PNEUMOCONIOSIS

FURTHER ROENTGENOLOGICAL AND PATHOLOGICAL STUDIES*

By HENRY K. PANCOAST, M.D., *and* EUGENE P. PENDERGRASS, M.D.

PHILADELPHIA, PENNSYLVANIA

IN 1925, at the request of the Editor of the *American Journal of Roentgenology and Radium Therapy*, we reviewed the roentgenological and pathological aspects of pneumoconiosis in a paper presented before the American Roentgen Ray Society and published in the Journal[90] of that year. A more complete presentation of the subject was made in a monograph[91] published in 1926. The condition has aroused a surprising amount of interest throughout the civilized world in the short time that has elapsed since then, and especially in this country. Papers have appeared in great numbers, further experimental work has been done and numerous investigations have been carried out, especially here, by federal and state health bodies in connection with many industries. For these reasons it has seemed pertinent to present a further and up-to-date review of the subject to the body of roentgenologists.

This increasing interest in the subject is a recognition of the great importance of the condition of pneumoconiosis as a more or less necessary risk of commercial development in the progress of civilization during recent years. This has led to the enactment of adequate compensation laws and regulations governing the adoption of safety measures intended to eradicate or modify the essential dangers of occupations by many countries, notably the South African Union, Australia, New Zealand, Great Britain, Germany and one of the Canadian Provinces. In this country we have no federal laws directly applicable to the enforcement of controlling measures or compensation. In only a few states is pneumoconiosis a compensable disease. Some states enforce regulations directed toward protection of workers. It is a condition which is all too prevalent in America without adequate oversight, but largely because of the geographical extent of this country and the scattering of the more or less dangerous dusty industries, there is a lack of knowledge of that prevalence and its seriousness.

As the roentgenological examination is the most accurate and satisfactory method of detecting the condition from its earliest to its most advanced stages and of studying its progress and its incapacitating effects, it behooves us as roentgenologists to be familiar with all of the phases of the disease, and not solely with the roentgenographic appearances with which all of us are more or less familiar. We must play a large part in the education and the publicity which are so much needed to overcome the ignorance still existing, even on the part of employers and employees. We will be called upon for our part in the program leading to the enactment of satisfactory compensation laws which are sure to follow in time. In the meanwhile, civil suits are increasing in number and we must train ourselves in order that we may be able to testify, when called upon, honestly and justly for the benefit of all concerned.

It has been our endeavor in this presentation to avoid as far as possible any repetitions from our previous publications, and references to them will be made only when it may be necessary to better explain the newer phases of the subject.

NOMENCLATURE

While it still seems probable that silica (SiO_2) is usually the active fibrosing agent in the condition which we recognize as essentially a pulmonary fibrosis, adherence to the general term of pneumoconiosis still seems advisable just as much now as at the time of our previous presentations of the subject. Some other dusts undoubtedly

* From the Radiological Clinic, University of Pennsylvania Medical School and Hospital, Philadelphia, Pa. Read at the Thirty-first Annual Meeting, American Roentgen Ray Society, West Baden, Ind., Sept. 23–26, 1930.

cause a fibrosis directly, and still others may either tend to retard the action of silica, as will be shown in connection with coal dust and clay, or enhance its action, as alkalies, as, for example, in the mixture of silica and powdered soap in scouring powders. Silicosis is the word much more frequently used and mainly because it is not such an unwieldy one, and is usually entirely descriptive of the particular phase of the condition under discussion. "Miners' phthisis" is written into the laws of South Africa, but is otherwise an obsolete term which is generally recognized as implying silicosis or pneumoconiosis. There is now reason to believe that silicates also produce considerable fibrosis through the elimination of silica or because certain silicates have a specific action of their own.

There is somewhat more reason to employ the occupational terms now than formerly because we have learned quite recently to realize certain peculiarities in connection with the dusts of those industries, even though the condition still remains silicosis or pneumoconiosis. For example, in anthracosis the action of the silica seems to be modified by the coal dust mixed with it. Moreover, coal dust alone may produce a mild fibrosis. Collis and Gilchrist,[14] in a recent investigation of coal trimmers working at the Cardiff docks, found that after many years of inhalation of coal dust alone in large amounts there was produced evidences of mild pneumoconiosis which presented the same roentgenographic appearances as silica. It has been suggested that clay has a similar effect in protecting the workers in some of the duties of the pottery industry, but not all of them. Chalicosis has been applied in the past to pneumoconiosis in the potter. This is not the only industry, however, in which clay is said to exert a possible protecting influence. This subject will be discussed further under pathology. There are certain very unusual features in connection with pneumoconiosis among asbestos workers, which, in recent years, have brought the term pulmonary asbestosis into active use. This industry will receive further attention under special occupations. There is probably more reason now to regard silicosis as an occupational term rather than a synonym for pneumoconiosis.

DUSTS

This phase of the subject needs very little further attention for the reason that silica (SiO_2) in a finely divided state, or possibly as derived from certain silicates, is still generally conceded to be the harmful agent in mosts dusts which affect the lungs in any serious way, although it is practically an established fact that other dusts such as coal, for example, may produce pulmonary fibrosis in a minor degree, but they are practically innocuous. As a matter of fact, some of them may exert a protecting influence against silicosis when mixed with silica. It is interesting to note, as mentioned elsewhere, that certain other dusts seem to enhance the dangers of silica. The most important pathological studies have been made in connection with silica.

The various industries in which silica is found in the elaborated dusts in dangerous quantities are too numerous to discuss in detail. Probably most individuals are not familiar with a large number of them. One is really amazed at the great variety of actual uses of silica in industry and the great opportunity afforded for its inhalation in dangerous quantities. The United States Public Health Bulletin No. 187[27] quotes a long table from Ladoo[61] giving the various uses of silica.

Watkins-Pitchford[121] states that it is not known how much silica dust is necessary in the lungs to produce actual silicosis. The lungs of individuals who are not silicotic have been estimated to contain 100,000 million silica particles, and probably those of silicotics contain millions of millions. A recent editorial in the *British Medical Journal*[21] states that we are greatly in need of some standard as to what constitutes an injurious amount of silica dust inhalation, otherwise legislation may become punitive in some harmless industries. The time and

intensity factors must be duly considered in any estimations. In connection with the investigations of the Barre granite industry by the U. S. Public Health Service[27] it was assumed that upon the basis of the studies of different groups of workers exposed to various concentrations of dust, 10 million particles containing approximately 35 per cent of free silica per cubic foot of air could be tolerated without great injury to the lungs over a long period. In other words, the individuals would develop only a mild fibrosis and not sufficient to predispose to tuberculosis. This assumption was reiterated by Russell.[97] The pneumatic tool operators in this industry were exposed to 55 to 64 million particles per cubic foot. Among other dusty industries investigated, a cement plant showed 26 million, hard coal miners and helpers were exposed to 231.5 million and soft coal cutters and loaders to 112.3 million particles of dust. For comparison, municipal street dust in congested districts was found to contain 4.1 million, whereas in residential districts it contained 1.8 million particles.

There are two general methods of determining the silica content of dust or of materials from which dust is derived: (1) The chemical method gives both free and combined silica. (2) The petrographic method shows the amount of free silica. The results of these two methods are being confused constantly. As an example of the differences in estimations, Russell[27,97] gives as the analysis of cement dust 21.2 per cent of free and combined silica and only 1 per cent free silica in the packing house. Granite dust showed approximately 70 per cent free and combined silica but 35.2 per cent free SiO_2.

At the present time there are two general methods of determining the concentration of dust in the atmosphere: (1) *Gravimetric.* A large measured volume of air containing the dust is passed through a filter, which retains the particles. These are weighed and the result calculated in terms of milligrams per cubic meter of air. The procedure weighs a large percentage of too great a size to be dangerous. (2) *Numerical.* Particles are collected from a small sample of air and measured and counted microscopically, and by calculation the number is estimated per unit volume of air. Neither method is perfect or accurate, but is relative.

PATHOLOGY

Familiarity with the progressive pathological processes is essential for the proper conception of the roentgenological appearances of pneumoconiosis. Moreover, the sequence of events proves to be a most interesting study, and also enables one to better understand the pathological processes following tuberculous infections of the lungs. The pathological features are best considered under the following headings, somewhat changed since our previous contributions because of a better understanding of the processes through further investigations: (1) The entrance of dust; (2) the "dust cell" or macrophage; (3) entrance of the "dust cell" into the lymphatic system of the lungs as a carrier of silica or other particles; (4) influence of the deposited silica in the production of fibrous tissue; (5) the action of silica; (6) elimination of dust; (7) the predisposition of the fibrotic and silica saturated lung to respiratory infections, especially tuberculosis.

1. *Entrance of Dust.* Most of the inhaled dust is removed from the inspired air by the protective mechanism of the respiratory passages before it reaches the pulmonary alveoli. The secretions of the nose, pharynx, trachea and bronchi retain a large part of it for subsequent expectoration or swallowing. The fine dust particles which get beyond the ciliated epithelium reach the alveoli and institute the pathological processes through irritation and a catarrhal process, attended by the proliferation of certain cells.

2. *The "Dust Cell."* Some of the proliferated cells in the alveoli become special phagocytes for the smallest dust particles, whether they be silica or certain other dusts. These are macrophages which have

been termed "dust cells." Suffice it to say that the consensus of opinion still regards these as endothelial in origin, derived from the walls of the capillaries and lymphatics which have intimate relations with the alveolar epithelium (reticulo-endothelium —Fried[25]).

Watkins-Pitchford[121] states that the size of the particles entering the lung tissue is limited by the capacity of the phagocyting endothelial cells which convey them into the lymph spaces and channels. Probably those over 10 microns in size are innocuous as they cannot be phagocyted. Most of those found in the lung are 0.5 to 5 microns in size. Any foreign particles of these sizes, if inhaled in sufficient quantities, will be carried into the lymphatic system, but with the exception of microorganisms and silica almost all others are harmless, or relatively so. According to their insolubility, they remain in the lymph structures and produce such relatively harmless conditions as anthracosis, aluminosis and siderosis.

3. *Entrance of the "Dust Cell" into the Lymphatic System.* Many dust-laden cells are expelled through the respiratory passages, but some of them enter the pulmonary lymphatic system. Mavrogordato,[70] Kettle,[59] Middleton,[74] Permar,[92] Gardner,[26] and others, have traced them from the alveoli throughout the entire lymphatic system of the lungs. These investigators studied the cells as carriers of dust particles and the subsequent effect of the silica up to the first stage of silicosis. The sequence of events in the history of the dust cells may be summarized as follows:

(1) From the alveoli the dust cells migrate toward the lymphoid deposits at the proximal ends of the lymphatic channels beginning along the alveolar ducts. These deposits are the first protective outposts of the lymphatic system.

(2) Some stop there and the lymphoid deposits undergo cellular proliferation and subsequent changes.

(3) Other cells reach the next larger deposits at the bifurcations of the bronchioles, bronchi and vessels, and some are stopped, with the same results.

(4) Some get by all obstacles and eventually reach the various pulmonary lymph nodes. Middleton[75] suggests that if the amount of silica reaching the alveolar walls is small, phagocytes are able to handle it, but if large, they become overloaded and are detained in their progress because the silica causes the cells to lose their motile power and they congregate in the lymph channels. Their deposit causes a reaction in the tissues and fibroblasts are produced, which ultimately become fibrous tissue.

(5) The blocking of lymph flow by dust cells, choking cellular proliferation and fibrosis at these various lodging places tends to cause stasis and favors subsequent additional lodgment.

(6) The aggregation of dust cells into groups and the infiltration and proliferation of other cellular elements presents an appearance which Mavrogordato[70] describes as pseudotubercles. It is in these areas, particularly, that the subsequent fibrosis takes place, as will be described later. Up to this time, the process, mechanically at least, resembles a tuberculous invasion, but the end-result, in pure silicosis, is always fibrosis and never caseation.

(7) In order to explain certain subsequent events, it was suggested by Mavrogordato[70] that silica tended to *preserve* the dust cells from autolysis and lymph digestion so that they could accumulate and primarily block the lymphatics. When these cells contained coal or some other dusts, however, they could be destroyed early and not block, and the dust could be set free and become deposited, with no specific action in causing fibrosis. Such action of the dusts upon the cells may or may not be an actual occurrence or even necessary to explain some of the more recent views in regard to the fibrosing action of silica.

Because the dust cell has been traced through various portions of the pulmonary lymphatic system as an intact cell, and was found still intact in areas where fibrosis was beginning, it was natural, at first,

to infer that this cell was *still alive* and was the original fibroblast in the process. If the preserving action of the contained silica is true, one can imagine how the dust cell may be found in all the various locations, but as a *dead* cell, an eventual dissolution would be expected, with the liberation of silica. These have been the more recent views, with the cell as simply a carrier of the silica to the points where it can exert its undesirable action to best advantage. Kettle[59] has expressed the view that when the cells reach the various points in the lymphatic system, the silica is dissolved in them and kills them, they tend to accumulate at the various points, the silica is liberated and then produces the tissue changes. As a slight modification of the theory, Watkins-Pitchford[121] suggests that when a cell dies and the silica is liberated, the particles are again engulfed by wandering endothelial cells or fixed connective tissue cells and the process is repeated, especially with pigment particles.

4. *Influence of the Deposited Silica in the Production of Fibrous Tissue.* Fibrosis is the essential pathological process in pneumoconiosis, and upon it the *serious* lymph block, the incapacitating features and the characteristic roentgenological appearances depend. The chronological order of changes may be summarized as follows:

(1) It begins in and around the various lymphoid deposits where the dust cells first tend to lodge. This corresponds to the *beginning* of a fine and practically microscopic nodular fibrosis along the course of the lymphatic system from the primary lobules to the pulmonary lymph nodes, and some of these areas represent the microscopic beginnings of what will later appear roentgenographically as the typical nodular type or stage of pneumoconiosis, when the process has continued until the small areas have enlarged sufficiently to become macroscopic and to cast definite shadows.

(2) In the meantime, however, the slight fibrosis, lymph block and pulmonary lymph node enlargement give rise, in slowly progressing cases, to the appearance which has been designated as the first stage.

(3) Simultaneously with the changes in the lymphoid deposits another process of fibrosis is instituted. The gradual blockage of the lymph channels by the enlarged nodules and surrounding reaction causes further clogging and accumulation of dust-laden cells in the channels and the deposition of silica in and around them through leakage of dust cells through the walls of the blocked vessels. Then a more diffuse fibrosis started in the *interstitial lung tissues.* The interalveolar tissue and interlobular septa thereby become thickened from clogged lymphatics and interstitial diffuse fibrosis, and they appear roentgenographically prominent, usually as a diffuse haze.

(4) In the *rapidly progressing* cases this may be the first noticeable change, instead of the nodular fibrosis, which may be practically absent or invisible. Thus, the terminal or third stage may appear without the interposition of the so-called first or second stages. This progression is rather characteristic of certain occupations, as granite cutters, for example. A variation of this may be characteristic of asbestosis and the fibrosis of sand pulverizers. In the great majority of instances, however, the nodular fibrotic appearance forms a well-developed and typical second stage. Disregard of the exceptional occupations has led to confusion in the proper understanding of the three definite stages noted in the general run of silicotic subjects, and which it seems necessary to replace with a new classification.

(5) As the normal hilumward lymph flow becomes blocked, there is instituted a backflow toward the subpleural lymphatics, and similar changes result in their distribution, resulting in more peripheral nodulation, thickened pleura, adhesions, and possible effusions rarely.

(6) In the case of weakly fibrosing dusts with very low silica content, the lymph flow is *maintained* hilumward, and the individuals may not progress beyond the first or slight second stage appearances in

thirty to fifty years. If the second stage or nodular appearances are present in such individuals, the nodules are centrally located, and not peripherally from backflow, at least until late.

(7) In the more rapidly progressing cases inhaling a high percentage silica dust some of the nodular fibrotic areas increase in size rapidly and tend to coalesce. In addition, the interstitial fibrosis in the interalveolar tissue and interlobular septa brings into prominence the diffuse fibrosis. All of these appearances may be presented within a period of ten years, or even less.

(8) The diffuse fibrosis may encroach upon the alveoli, bronchioles and vessels and also destroy the elasticity of the lungs. This is a far more serious process than the nodular fibrosis. Which of the two gains the ascendency first will depend largely upon the volume of dust inhaled and the resulting rapidity of the disease in its progress.

(9) In some advanced cases with third or final stage changes, areas of massive fibrosis of considerable size may develop and present an appearance like consolidations. It is believed by many that these consolidations are usually associated with a mild tuberculous infection.

(10) In the description of any condition in which several simultaneous and interrelated processes are described and must be made to conform with the sequence of results expressed in numerical order typical cases, the one to one other is usually difficult of description in a manner readily understood. This is especially so in connection with silicosis. It should be borne in mind that there are critical periods in the fibrosis in certain histological areas wherein definite appearances stand out prominently in the *typical* case: (*a*) The still open but more or less clogged lymphatic channels leading to the central nodes plus *microscopic* nodular fibrosis represent what has been called the first stage; (*b*) the *macroscopic* nodular fibrosis of the so-called second stage; (*c*) the diffuse interstitial fibrosis or conglomerate nodular fibrosis or both of the third or terminal stage. The rate of dust intake may upset the usual numerical sequence of results with the *apparent* elimination of the first or the second stages or both. The omission of the second stage is more difficult to understand than that of the first.

5. *The Action of Silica.* At the time of our previous presentations[90,91] it had been the prevailing opinion that the preserved dust cell did not die but became a fibroblast. Just at that time there seems to have been a decided change of opinion, especially on the part of Mavrogordato[71] and Kettle,[59] in regard to the ultimate fate of the dust cell and the exact institution of fibrous tissue formation.

To recapitulate, according to modern views, the dust cell moves and is carried to the destinations previously mentioned. The silica is slowly dissolved within it and kills it. It may die on the way, and if so it escapes autolysis for a while because of the preservation afforded by the contained silica. The dissolved and undissolved silica is eventually set free by subsequent destruction of the cell and is then further dissolved by the alkaline body fluids and the disastrous results follow.

Kettle,[59] in 1926, on reviewing the effects from the experimental injection of *soluble* silica into animals and comparing it with the injection of *amorphous* silica concluded that chemical action per se was the cause of ultimate fibrosis without the interposition of any specific dust cell *except as a carrier*. It has been proved satisfactorily that silica is soluble in alkalies and the body fluids. The previous experiments with injections into the subcutaneous tissues of animals of *colloidal* silica produced characteristic reactions of an area of central necrosis, a surrounding zone of leucocytic infiltration, still further out a zone of spreading secondary necrosis, and surrounding this an area of organizing inflammatory fibrosis. Later on the necrotic areas were absorbed and replaced by invading fibrous tissue, resulting eventually in a fibrous scar. The same effects were induced, though in a longer

period of time, by the injection of *amorphous* silica. Furthermore, none of the supposed insoluble silica could be found subsequently, indicating that it had been dissolved. On the other hand, oxides of aluminum or iron and carbon were found to remain permanently undissolved and recognizable in the tissues. Similar experiments with mine dusts containing silica gave comparable results. Further interesting experiments with collodion capsules filled with silica and embedded in the connective tissues of animals produced similar results. The tissue lymph was able to pass through the semipermeable membrane and dissolve the silica and the solution passed back into the tissues. Control capsules filled with calcium chloride produced no changes comparable to those induced by the silica capsules.

Still more recently, Heffernan and Green[44] (1928) and Heffernan[42] (1929) have taken issue with some of the deductions based upon the experimental work of Gye and Purdy[33,34,35] and Gye and Kettle[32] that silica is a soluble protoplasmic poison. They do not regard this view as compatible with the supposition that the tubercle bacillus shows greater proliferative powers in silica coagulum than in tissues without silica. They refer to the investigations of many others showing that silica is a normal constituent of the human body, even lung tissue, being taken in with foods; that it is prevalent in connective tissue, especially newly formed scar tissue, including that around healing tuberculous foci; that it has even been administered in the treatment of pulmonary tuberculosis. It is not a poison, of course, under ordinary conditions.

In order to understand better the foregoing experimental work and the more or less theoretical discussion which follows, it seems advisable to explain the colloidal states in an elementary manner. Colloids exist in three states—as suspensoids, sols and gels. A *sol* (solution) is that state of a colloid suspension in which the particles have taken up H_2O physically, but not chemically as in a hydroxide. Evidently in the case of silica this can take place only in an alkaline medium. A *gel* (coagulum) is a state in which some of the H_2O of the sol is lost. The physical state of silica gel may render it inert because it cannot then attack cells or exhibit the same adsorptive properties of the sol. Adsorption is a process whereby other substances adhere to colloid particles physically but not chemically.

Belt[4] states that colloidal silica or silica sol ($Si(OH)_4$) is the most readily formed soluble derivative of silica and is a poisonous substance. If colloidal silica is left to stand, it becomes altered by dehydration into silica gel, H_2SiO_3, or metasilicic acid, which is apparently nontoxic. This reaction is irreversible. Silicosis is progressive, theoretically, as long as undissolved silica remains in the tissue.

Heffernan calls silicosis a gross overproduction of fibrous tissue. A brief résumé of his hypothesis in regard to the exact action of the silica is as follows: He regards the *hydrated colloidal silica* first produced in the dust cells, not as a soluble protoplasmic poison, but simply as an active colloid with a selective adsorptive action which upsets the equilibrium of the complex colloidal system of living cells just as certain substances like tar induce cancer. The pathology begins when the macrophages containing particles of silica come to rest in the lymph spaces of the lungs. The particles are then gradually hydrated into colloidal silica which exerts its adsorptive powers on the protoplasm of the dust cells. The activity of the silica then spreads to neighboring cells, which are in turn similarly affected, leaving the cell "ghosts" surrounding the central mass of silica sol plus protoplasmic fluid. This is the "rich pabulum" in which the tubercle bacillus thrives so well. These "ghosts" and the cell stroma form the new fibrotic wall surrounding the central mass, the whole constituting the pseudotubercle of Mavrogordato and others. With the conversion of the silica into an eventual coagulum or gel, the activity subsides and a fibrous nodule is left,

except where tuberculosis intervenes. Thus silicosis is the result of a local physio-chemical action of hydrated silica on pulmonary tissue. The speed of development depends upon the rapidity of formation of fresh silica hydrosol. Alkalies accelerate the formation of silica hydrosol (see especially notes on silica scouring powders), whereas carbon, coal dust and clay retard it or favor the coagulation of it. This hypothesis certainly helps to explain the apparent protective action of coal dust, clay admixtures with lime stone (Kindel and Hayhurst,[60] and Hayhurst, Kindel, Neiswander and Barrett[41]) and the protection of some siliceous brick workers (Heffernan[43] and Smith and Collis[106]).

Belt[4] suggests that the alleged protective or inhibitive influence of dusts such as coal, shale and certain clays, may lie in the fact that they favor a steady exodus from the lung of phagocytes also carrying silica. The proof of the elimination of such dusts is to be found in the expectoration of coal dust many years after cessation of work in the mines. Gardner[29] states that phagocytes behave quite differently to various types of dust. They ingest quartz slowly, and few particles enter any one cell, and the motility of the cell is not impeded or even may be accelerated, and it enters the lymph spaces readily. Carborundum and granite dust, on the other hand, are ingested rapidly and the cells become overloaded. Hence they may not migrate so rapidly and may remain within the air spaces three or four years. Those cells which happen to take in only a few particles by chance, do move and localize like the quartz containing cells. These phenomena may explain some of the differences in the reactions of lungs to different dusts.

Heffernan thinks that silicates may undergo changes similar to those of silica, such, for example, as asbestos, which is a magnesium silicate, and which is known to cause fibrosis of the lungs. This may seem somewhat paradoxical when he states that clay, a hydrated silicate of aluminum, tends to retard the progress of silicosis. On the other hand, kaolin and clay are said to produce a mild fibrosis. Although Watkins-Pitchford[121] has stated that silicates produce no specific effect, we must believe that at least some of them do, in the light of our present knowledge. Gardner,[28,29] in his experiments on guinea pigs, was able to reactivate tuberculous lung lesions by inhalations of quartz, carborundum and granite dusts. He intimates that it is not impossible that the alkaline body fluids may even attack and dissolve silica from the silicon carbide or carborundum. There are some very interesting features in connection with the fibrosis found among asbestos workers that deserve special mention, and they will be discussed in connection with the details of the asbestos industry. It is questionable whether or not we can correctly apply the term silicosis to the fibrosis caused by asbestos dust because the condition is not due primarily to silica. Badham[1a] suggests the name "silicatosis" to such types of pneumoconiosis. He believes that a fine fibrosis of the lungs often found in metalliferous and coal miners and workers in other industrial activities in New South Wales is due to silicates in most instances, and not to silica. He reported the death of a man with pulmonary fibrosis, proved by roentgenographic study, resulting from the inhalation of mine dust containing silicates but no silica. While the final symptoms are said to have been similar to and the clinical history to closely resemble those of the broken Hill district miners who had died of silicosis, there was no autopsy proof that this patient's death was due to that condition.

6. *The Elimination of Dust.* While there has been a well-established belief that individuals who have not progressed to the point of an incapacitating fibrosis may show clinical and roentgenographic improvement after cessation of their occupations, we do not believe that actual fibrosis will disappear. Wainwright and Nichols,[120] in 1905, when investigating the condition among the anthracite coal miners in the Scranton district found, on examining the lungs of miners who had engaged in

other occupations for a number of years after cessation of mining, that the alveolar cellular aspect of the condition had disappeared, but the deposits of dust and the excess of connective tissue were still present in the alveolar walls, interlobular septa and the glands.

It may be true that the lung can free itself of silica to a certain extent, first, by a reversal of the process of entrance, and, second, through the lymphatic system to other parts of the body. Riddell[94] and Collis[13] have found silica in abnormal quantities in the liver, spleen and kidneys after autopsy. Mavrogordato[70] has shown that swallowed dust may reach the lungs. He also found that at least six months may intervene between the admission of silica and the production of definite fibrosis, indicating a definite latent period. He has found silica in the sputum six months after its inhalation. We know that coal dust may be similarly found two to four years after cessation of mining and exposure. Collis[13] has suggested that silica in solution may leave the lungs slowly, and even be eliminated by the kidneys and cause fibrosis and chronic nephritis. All of the silicotic groups studied by him showed some excess mortality from chronic nephritis and this was highest where the excess mortality from silicosis was greatest.

Notwithstanding these illustrative facts, we believe that silicosis, once established, is usually progressive, and that much or all of the supposed improvement following cessation of occupation by even the moderately advanced silicotics is largely imaginary. There may be some temporary improvement but it is not lasting. The progress may not be so rapid as would have been the case had the occupation been continued. We have been impressed by the large number of individuals who, many years previously, had worked in silica dust elsewhere, and then came to the city, although not then incapacitated in any way, but several years afterwards, free from dusty occupations, developed respiratory difficulties and were referred to us for examination. They showed advanced silicotic changes. Some of these cases may, of course, have had an undiscoverable tuberculous infection. Tattersall[115] definitely states that a change in occupation does not prevent progression of the condition. Middleton[75] calls attention to two factors in the progress of silicosis—a latent period and cumulative action. Fibrosis proceeds if sufficient silica has been taken in during the latent period, even though the inhalation of the silica stops. If it stops before enough is taken in to ultimately cause disability after the latent period has passed, the condition would probably not go on to disability. This is not likely in a very dusty atmosphere. This sounds like sensible doctrine.

The men who stop work are usually more or less subjected to tuberculous infection later. Mavrogordato[71] states that apart from such infection, the silicosis is non-progressive if dust exposure ceases. Attention has been called previously[90,91] to the report by Watkins-Pitchford[109] that many of the South African miners who went to the late war without traces of silicosis came back with well-developed evidences of the condition. He believed that the determining factor in the progression was almost certainly a tuberculous infection.

7. *Predisposition of the Fibrotic and Silica Saturated Lung to Respiratory Infections, Especially Tuberculosis.* All reports by those who have made extensive studies of silicosis agree that the workers who develop the condition with any degree of rapidity are predisposed to respiratory infections, especially bronchitis, pneumonia and tuberculosis. There have been a few additional views expressed as to the cause of this predisposition since our previous contributions. Gye and Kettle,[32] Kettle[59] and Collis[13] have agreed, as a result of experimentation, that the products of cellular destruction make a most favorable soil for the proliferation of the tubercle bacillus. Heffernan[42,43] does not differ essentially in his views except as to the question of silica being a definite cell poison.

It should be borne in mind, as Willis[126]

states, that the bacilli and the dust go to the same place in much the same way, and begin work in the same localities. Although the fibrosis of pneumoconiosis may tend to limit the spread of tuberculosis, and may be in a measure protective, still it is equally true that the fibrosis tends to localize and hold the organisms because of interference with lymph drainage.

Belt[4] states that *advanced* silicotics more often contract tuberculosis than pneumonia, but the latter is the greater hazard in earlier cases when the inhalations are copious and the fibrosis slight. We believe that this is a very important statement for the reason that pneumonia was said to have been the most frequent cause of death in the group of sand pulverizers we have recently examined, and in whom the inhalation of dust was enormous, but the infection occurred long before the fibrosis had reached an advanced stage.

On the basis of animal experimentation, Gardner[28,29] believes that it is quite likely that inhaled dusts of certain types may of themselves light up preëxisting quiescent foci of infection, either through direct action on the bacilli or through altered metabolism of the cells with resulting formation of substances favorable to the organism. He first infected guinea pigs by inhalation of tubercle bacilli of low virulence which consistently produced tubercles which would caseate, retrogress and finally heal. At serial intervals after infection he exposed these animals to quartz, carborundum and granite dusts until they died or were killed. All three of these dusts stimulated the multiplication of bacilli in healing tubercles and caused progression of the lesions in 73.6 per cent of the animals exposed to quartz, in 31.8 per cent of those inhaling carborundum and in 26.3 per cent of those receiving granite dust. Not all dusts do this, notably coal and marble, but silica and some silicates do. Renewed activity took place only in tubercles containing ample amounts of dust. These experiments suggest, though do not prove, that at least some of the tuberculosis among workers in excessive dusts is due to the reawakening of previously active but quiescent lesions.

Belt[4] states that their autopsy observations showed that caseation always took place in the lung areas which remained air containing, whereas fibrosed patches invariably escaped necrosis. Fibrous nodules were often found completely surrounded by caseation. He never found the tuberculous process starting within the fibrous lesion. The points most vulnerable to infection were the "silica nests" where unaltered silica was collected in large amounts in avascular areas around completely fibrosed or healed necrotic lesions of silicosis and where further tissue reaction was impossible. He believes that marked progression of disease after cessation of work is evidence of either increased fibrosis or tubercle infection. An individual leaving his dusty occupation and having progressed to the stage of completed fibrosis (no remaining silica nests) is no longer a special tuberculous risk. He interprets Heffernan and Green's views as implying that colloidal silica, by its powers of adsorption, binds the complement of human serum so that antibodies are prevented from attacking the tubercle bacilli.

COINCIDENT TUBERCULOSIS

Coincident tuberculosis is one of the most serious phases of silicosis, and has been a very frequent cause of death, although the latter condition itself may prove fatal. As tuberculosis affects particularly those in whom silicosis develops most rapidly, it can be controlled to a certain extent, though not entirely, by measures directed against the rapid progress of the predisposing condition. Elimination of the tuberculo-silicotic individual from contact with his fellow workers is also a most important preventive measure. He is a serious menace to his coworker. This is not necessarily the case with his family, however, because he develops tuberculosis later in life than the average non-silicotic individual (Russell,[96] McFarland,[69] Collis[13]) and when his children are older and less

susceptible. The average age incidence is placed by many at fifty to fifty-five years. Watkins-Pitchford[121] has stated that there was no instance known to the South African Board of a wife having developed overt tuberculosis from her silicotic husband, even after successive marriages. The Miners' Phthisis Act of 1919 has had to prevent matrimonial speculation of remarriage by cutting off the widow's pension if she remarries. The age incidence of tuberculosis is probably lower among the native miners of South Africa because of the prevalence of that infection among them, so that they develop it earlier.

The individual debarred from work because of tuberculosis, especially without incapacitating silicosis, receives specially adjusted compensation in countries in which satisfactory compensation laws are in force.

The question of specific protection against coincident tuberculosis among coal miners and in certain other dusty occupations in which the workers are exposed to considerable silica will be discussed more in detail in connection with the various dusty industries. The mixed dusts, particularly coal and clay, seem to be associated with a lower incidence of tuberculosis, particularly if they exert a retarding action upon the development of silicosis, and probably for the same reason, although this is not certain.

Watkins-Pitchford[121] was responsible in 1927 for the rather surprising statement that in the majority of cases among the Rand gold miners the determining cause of the appearance of silicosis in its simple form has of late years been a tuberculous infection rather than excessive silica particles. There are two reasons for this: first, the success of preventive measures against silicosis and, second, the appearance of tuberculosis among the native African miners in almost an endemic form of the disease.

The Report of the Miners' Phthisis Medical Bureau[79] for 1927 states that while simple silicosis is being brought under control, the tubercle bacillus has now become the great problem, and the prevention has changed from an engineering to a medical problem.

Cluver[10] quotes Cummins as classifying tuberculosis among the Rand miners as follows: natural and modified. The natural or infantile type is a generalized disease leading to a caseo-necrotic process primarily in the lymphoid tissue and then becoming generalized through the blood stream. This is the condition found in the native race having no contact with Europeans. As many as 200,000 natives are employed in the Rand mines and the average of yearly detected cases of tuberculosis is about 1,400. The disease is endemic among them and is carried from one miner to the other. Mavrogordato[71] makes a similar assertion in calling attention to the fact that tuberculosis in the native African silicotic does not resemble the usual chronic type of the adult, but is more that of the acute form of young children. This would be expected if we are to regard the native African as a nonsensitized individual.

An excellent example of the predisposition to tuberculosis and other respiratory

AVERAGE DEATH RATE PER 100,000 MINERS AND GENERAL POPULATION IN CERTAIN STATES FOR 1917–1920

Diseases	California		Colorado		Missouri		Nevada	
	Metal Miners	General Population	Metal Miners	General Population	Metal Miners	General Population	Metal Miners	General Population
Silicosis	34.66		609.32				95.22	
Tuberculosis	664.45	155.7	154.40	205.60	1946.70	117.3	298.06	No data
Influenza	162.56	124.6	644.72	177.85	602.24	102.5	149.23	
Pneumonia	521.70	133.5	2182.09	184.87	338.10	178.8	656.98	

infections is shown in the preceding abstracted table of Sayers[98b] prepared for the United States Bureau of Mines in 1925: It will be noted that there is a wide variation in the death rate from, and obviously, the predisposition to, respiratory infections in the states included in the above abstracted table. This is due very largely to the character of the rock as to free silica content in the different localities. Inspection of the very complete mining map of the United States Bureau of Mines showing the character of rock encountered at the different mine areas indicates that in the same mining industries located quite close together there is often a very great difference in the amount of silica to which the miners are exposed.

UNUSUAL COMPLICATIONS

In our previous communications we reported one case of supposed left phrenic nerve paralysis. Subsequently, through the courtesy of Dr. Russell,[96] we had the opportunity of examining numerous roentgenograms of Barre granite cutters with advanced silicosis. We noted among these several instances of extremely high left diaphragmatic dome. It is apparent that the left dome is susceptible to greater elevation than the right, through the agency of extreme fibrosis. It is possible that our case was an example of this kind and not one of phrenic paralysis (Fig. 10). Nevertheless, we believe that it is possible for this complication to occur.

We have found no reason to alter our previous statements in regard to the possible predisposition to primary lung cancer or mediastinal tumors. It is a well-recognized fact that primary lung cancer is rapidly increasing in its incidence, and a diligent search is being made for a predisposing factor. It is to be expected that an occasional case will occur among the large body of silicotic individuals, in the natural course of events. Among the many hundreds of silicotics we have examined, or whose roentgenograms we have had the opportunity of studying, we have never seen a case of this tumor, nor have we seen changes of silicosis in any of the lung cancer cases we have observed. Several instances of mediastinal tumors, either lymphosarcoma or Hodgkin's disease, have come to our attention, the cases being referred for examination or treatment, but even with the silicotic appearances they presented, there was no reason for believing that the growths were otherwise than coincidental. We have

Fig. 1. Terminal diffuse fibrotic stage of pneumoconiosis with consolidations of fibrous tissue simulating mediastinal tumor by their location. Male, aged sixty, worked in coal mine for twenty-five to thirty years, seventeen years before examination. Has myocardial decompensation. This patient received deep roentgen therapy but unchanged appearance led us to believe the shadows were due to fibrosis and not to growth.

seen in many cases of third stage silicosis areas of massive fibrosis which were almost undistinguishable from primary lung or mediastinal tumors, but we were never able to select one in which we were positive that the consolidation was neoplastic or which turned out to be so eventually (Fig. 1). Ewing[23] quotes Wolf as stating that rupture of anthracotic nodules into the bronchi

is responsible for some cases of bronchial carcinoma, and calls attention to the much quoted cancer of the Schneeberg miners. Watkins-Pitchford[121] reports that in one case the appearance of silicosis was simulated by primary cancer.

Thickened pleura is an expected part of the process of silicosis and is not a complication. The visceral pleural thickening is always well shown when a spontaneous

Fig. 2. Advanced pneumoconiosis associated with passive congestion. Note that the heart is within normal limits of size in this sagittal view, but in the lateral view it was abnormally enlarged. The lateral view is usually necessary for estimation of cardiac dimensions in silicotic subjects. Male, aged fifty-nine, with myocardial disease following coronary occlusion and diabetes. General edema. Mined hard coal for eight years but not for past twenty-six years. What is probably a nodular predominance is apparently intensified, with the appearance like terminal diffuse fibrosis produced by passive congestion.

pneumothorax has occurred. This is a rather frequent accident, and usually the partial lung collapse is seen in the upper chest or upper lobe region, probably where adhesions are not so pronounced. Dr. Russell[96] showed us several roentgenograms of cases among the granite cutter group, and the pneumothorax was in the upper lobe region in all but one. All of our own cases have had the condition in this region. We have never observed a pleural effusion which we could attribute to silicosis. Watkins-Pitchford[121] states that pleurisy in a silicotic individual is invariably tuberculous in origin. We would, of course, make an exception of the pleural complication of pneumonia.

Lahey[62] mentions chalicosis as a cause of traction diverticula of the thoracic esophagus.

It is uncertain just how much the appearance of silicosis may be simulated by coincident syphilis of the lung. The incidence of pulmonary syphilis is denied by many, and the roentgenologist is rather loath to make a diagnosis of a pulmonary syphilitic lesion. Watkins-Pitchford[121] states that the roentgenographic appearance of the South African type of tuberculosis with silicosis has been simulated by syphilis and the appearance has cleared up in a few instances following treatment. The question arises as to the effect of antiluetic treatment on the fibrosis of silicosis. It is inferred that every silicotic individual with a positive Wassermann reaction must await the results of treatment before a final decision is reached as to the degree and extent of the silicosis.

It may be pertinent at this time to mention the possible combined effects of passive congestion from cardiac decompensation and silicosis. In the presence of frank decompensation, the accompanying passive congestion would seem to intensify the appearances of any of the stages of silicosis. The appearance of both conditions is very much the same in the so-called first stage of the latter, and may be almost or quite indistinguishable. We have seen a case of apparent third stage silicosis in whom the obvious third stage appearances may have been intensified or those of the second stage made to simulate the former by passive congestion (Fig. 2). Moreover, the

terminal lung change in passive congestion may be a fibrosis which could be superadded to that of silicosis. Certainly the lymph block of silicosis would be increased by passive congestion. In our case cited, the heart shadow was within normal limits of size in the posteroanterior view but was too large in the lateral view. It is a striking feature that advanced silicotics who have developed myocardial degeneration do not, as a rule, present the roentgenological evidences of a large cardiac shadow in the sagittal view, but it may be demonstrated in the lateral direction.

RACIAL STATISTICS

The only writer who has insisted upon any relation between race and the time of incidence or the severity of silicosis has been Jarvis,[53] in referring to the Barre granite cutters. His observations have not been confirmed by later study of granite cutters. We have observed no such connection in our experience. Watkins-Pitchford[121] states that in his experience there is no predisposition of age, race or individual characteristics except the racial susceptibility to tuberculosis. There is a definite susceptibility on the part of anyone who has had previous tuberculosis, even though it may be completely quiescent. It is always very important to inquire carefully into the question of previous occupation before drawing any conclusions as the effect of race.

SYMPTOMATOLOGY

As roentgenologists, we are not so much concerned with symptomatology because, in uncomplicated silicosis, we are not dealing with a condition in which a differential diagnosis must depend upon correlation of clinical data, as a rule, beyond a knowledge of occupation, past and present, and the single symptom of dyspnea. This is fortunate, in a way, because the symptomatology, especially in chronic cases, is rather meager until the late stages. Hence the great value of the characteristic roentgenographic appearances which make the diagnosis so easy. On the other hand, we do not have cases referred to us for examination in regular practice until the late stages, when symptoms are present. Most roentgenologists are more familiar with the appearances of these late cases than they are with the earlier ones, unless individuals are referred in groups from different industries, and all phases of the disease can be studied.

In chronic cases, about the only early symptom is cough, which is very often unproductive. The prominent symptom of dyspnea is a late manifestation, coming on after long exposure, anywhere from five up to forty to fifty years.

In acute cases, dyspnea is a relatively early symptom, usually coming on after from one to five years. In the late stages there is apt to be some cyanosis, elevation of temperature, considerable loss of weight, and toward the end, an acute illness terminating in death. Middleton[75] calls attention to the fact that the symptomatology in the late stages of the acute cases closely resembles that of miliary tuberculosis. Symptomatology is considered further in connection with pulmonary asbestosis in order to avoid duplication.

ROENTGENOLOGICAL APPEARANCES

No one disputes the fact that a properly conducted roentgenological study is the most satisfactory and the most accurate means of diagnosis and of follow-up records. Unfortunately, a large part of the routine studies of different industries in this country has been carried out by very inferior roentgenological technique. This has been unavoidable in many instances because much of the routine investigation of dusty industries has had to be carried out in inaccessible localities with portable equipment. It is quite remarkable, however, that so much can be learned from mediocre roentgenograms, but they have no place from the medicolegal or compensation standpoints. We believe that every case should receive the same careful examination that would be given to any other chest condition, with both roentgenoscopic

and roentgenographic studies. Roentgenoscopic observations are very valuable in determining respiratory capacity. The experiences of examining boards in South Africa and other countries have proved that no compensation measures can be carried out justly or satisfactorily without careful roentgenological studies. In South Africa, for example, every miner must be examined before he is allowed to go into the mines, and every six months subsequently.

A thorough clinical examination is essential in every case, especially for purposes of differential diagnosis, the determination of actual or impending incapacity and for the detection of evidences of tuberculosis.

ROENTGENOLOGICAL STAGES OF PROGRESS

Roentgen appearances represent pathological changes, and at first it seemed logical that the stages of progress of these changes should be based upon a sequence of progression which could be shown by such simple means as the roentgenogram. A clinical classification must be based upon phenomena such as progressive dyspnea and incapacity for work and certain clinical signs. Even these, however, seemed to follow the roentgenographic demonstration of progression of the pathology rather closely, when the first classifications were based upon similar industries.

It is unfortunate that the roentgenological classifications of many other countries have differed from that of our own. In the United States it has been the custom to follow the roentgenological classification of Lanza and Childs,[66] who divided the condition as shown by the roentgenogram into the three well-known stages, designated numerically. We have followed this until the present time when we believe this classification is no longer feasible. In South Africa where the disease received probably the greatest amount of study in the early years of our more extensive knowledge of it, three pathological stages were first recognized—early, intermediate and advanced silicosis (Watt, Irvine, Johnson and Stewart[123]). The roentgenographic appearances ascribed to these were quite similar to those of our own three stages. Later on, the condition was *legally* divided into three *clinical* stages —ante primary, primary and secondary. Roentgenographic appearances were grouped to conform to these in showing progression or extent. Compensation laws elsewhere, as in Ontario, have been based to a considerable extent upon the highly successful ones in force in South Africa, and as a result, the legal classification of this disease has been followed, and the roentgenological one with the same designations of stages has been adopted, which is quite natural. With no federal laws in this country directly governing the condition, and no clinical classification of the disease, the roentgenological classification first adopted has held priority. It would have been a simple matter, of course, to change ours to conform with that of other countries, should occasion have arisen, but we seem to have preferred our own way so far.

A brief résumé of the roentgenological stages of silicosis as they have been described in this country will be necessary in order to make comparisons with those in use elsewhere:

First Stage. This stage has been characterized roentgenographically by a definite increase in the prominence and extent of the hilum shadows, an increased prominence and thickening of the trunk shadows and a greater prominence of the linear markings of the peripheral zone. Enlarged glands may be interpreted in the hilum regions (Fig. 3). This stage must be subject to certain modifications. When examining, at a single sitting, a large number of carefully made stereoscopic roentgenograms of the chests of individuals who have worked for a comparatively short time in the midst of large quantities of dust, or even those who have worked longer in low concentration silica dust atmospheres, we have frequently detected appearances in the central portions of the lungs, usually more or entirely on the right side, consisting of a slight haze, with or without fine

lines. Within these areas there occasionally appear a few small, faint, hazy spots, which are probably the beginning of lymphoid deposit enlargement. In a large number of these cases the definite appearances of the first stage, as they have just been described, were not apparent. In a flat roentgenogram, these hazy areas often have the appearance presented by a very small female breast or a pectoral muscle in a male, but in the wrong locality. The appearance could be overlooked very easily were one not on the lookout for it. Our attention was first called to this appearance by Brink and Riddell[7] of Toronto. At that time we were under the impression that it corresponded to the ante primary stage of South Africa, as stated in our previous communications, but we have since concluded that this is not the case. We were fortunate later in making a collective observation of a number of examples of this appearance among the roentgenograms seen in consultation with Dr. A. R. Smith in connection with her excellent work in the study of silicosis among the rock drillers and excavators in New York City,[104,105] and also among a group of sand pulverizers we recently examined.

This appearance is probably due to the beginning of the interstitial fibrosis and of the visibility of a few of the individual nodules. A more recent study of this appearance and a better understanding of the ante primary stage of South Africa rather convinced us that it really belonged to our first stage as a variant, although Dr. Smith[105] has suggested that it be made a separate stage. It certainly cannot be made to conform with the ante primary stage, which it antedates. Öhman[85] has made four stages which would practically correspond to the suggestions of Dr. Smith. One who has observed the effects of dusts in many occupations will find that individuals who follow certain dusty trades do not present progressive appearances that run true to form or that can be made to conform to the usual general stages for the reason that there are types of the condition peculiar to certain industries.

The general appearances of this first stage are not characteristic of pneumoconiosis alone, but may be simulated by many other conditions, such as, especially, passive congestion, acute or chronic respiratory infections, chronic bronchial catarrh and bronchiectasis. Moreover, the hilum and trunk shadows are subject to considerable normal variations in appearance in the adult.

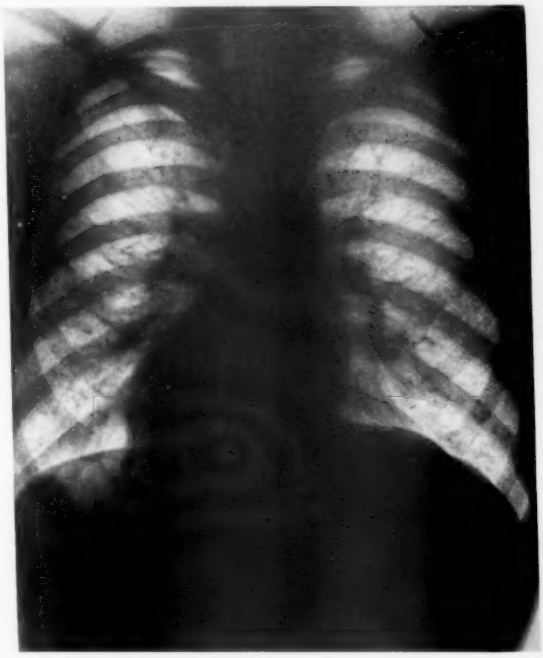


Fig. 3. The so-called first stage (American classification) of pneumoconiosis. Male, aged twenty-nine, coal cutter for eight years. Note the prominent trunk and hilum shadows, without nodulation.

As a numerical stage, this one implies, theoretically at least, an early period in progression, yet individuals may remain in it for years or indefinitely. As the appearances of a typical first stage, with prominent hilum and trunk shadows and linear markings, are not characteristic of pneumoconiosis alone, we are inclined to doubt the fairness of giving this stage a definite medicolegal status or of using it as a basis for compensation. Certainly it should not be so used unless the diagnosis has been based upon serial study and by stereoscopic

roentgenograms made by the most careful technique. The exposures must be short, 1/10 of a second or less, and all serial examinations should be made by an identical technique. Trunk shadows are cast mainly by blood vessels accompanying the bronchi, and pulsation is likely to increase the width of their shadows, hence the necessity for very short exposures. Conditions simulating this stage must be excluded. It seems

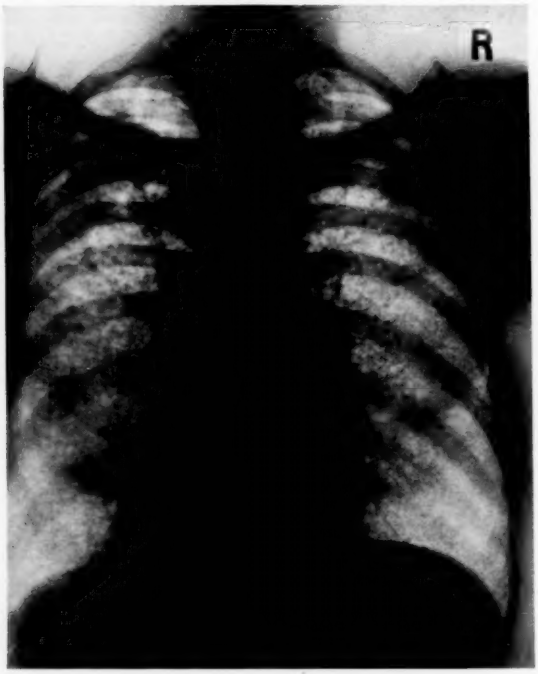


Fig. 4. The so-called second stage (American classification) of pneumoconiosis. Male, aged fifty-eight, coal miner for forty years. There is diffuse nodulation throughout both lungs. The densities of the subclavicular areas may be evidences of beginning terminal diffuse fibrosis, of the third stage, or of tuberculosis. The former is more likely as there is also a diffuse haze in the mid lung field on the right and to a less extent on the left, indicating late or advanced interstitial fibrosis. Diaphragmatic excursion was still good, however.

certain that an individual showing only this stage is not likely to have any incapacity, and unless he has been inhaling a large quantity of silica for a very short time, he is not likely to have acquired any predisposition to tuberculosis. The South African and Ontario ante primary stage appearance is a much more definite evidence of silicosis than our first stage because it includes in addition to the increased prominence of trunk and hilum shadows an early but very apparent nodulation that is characteristic of the condition. It might be stated at this time that we no longer support the numerical stages so long in use in this country, but we offer a substitute classification later.

Diagnosis. There should be no difficulty in determining a coincident tuberculosis in this stage.

Pathology. These first stage appearances correspond exactly to the pathological changes of this period. The large numbers of dust cells that have reached the pulmonary lymph nodes institute more or less fibrosis and enlargement of these glands, hence the denser and larger and more homogeneous hilum shadows. A lymph block in this direction is also instituted by the fibrosis in the glands. Lodgment of cells in the peribronchial and perivascular lymphatics causes, with the lymph block, the thickened trunks and prominent linear markings. The appearance may be due to the inhalation of a large amount of dust for a short time or a small amount for a long time, usually the latter. Interalveolar, interlobular and subpleural fibrosis may have started, and may be noticeable as a slight subpleural haze in clear roentgenograms, and represents a transition to subsequent stages. The additional appearances to which attention has just been called as a variant are probably due to coincident early interstitial fibrosis.

Second Stage. This most typical stage has been characterized by the distinctive distribution of small, rounded densities, varying in size from a pinhead to a pea, and distributed throughout both lungs (Fig. 4). Usually they are due entirely to small fibrotic nodules, except, occasionally, when metallic deposits may help to cast the shadows. This possibility has been confirmed recently by Bohrod.[6] The nodules appear first on the right side, around the root of the lung, and usually become quite

perceptible here before they are seen on the left side. This predominance is apparent until the distribution becomes quite general throughout both lungs, and then there is no appreciable difference. The spots are always more numerous around the roots and less in the apical regions and bases. The densest and most sharply defined nodules are usually found in association with the more rapidly fibrosing dusts, such as those to which many abrasive tool grinders are exposed. In workers exposed to low percentage silica dusts and to fibrosing dusts not containing silica, and causing very slow fibrosis, as in cement and some asbestos occupations, the nodules are less dense and less sharply defined (Fig. 4). There is always more or less evidence of diffuse fibrosis present, as a continuation of that often visibly started in the first stage, and as a forerunner of the essential process of the third. It may not be apparent because of emphysema. When not apparent, its presence may be suggested by lack of lung expansion and diaphragmatic excursion, or sharp peaking of the domes.

Theoretically, one would expect this second stage nodulation to be superimposed upon first stage appearances, but very often the latter are not apparent. They may be obscured by emphysema, but this is not the sole cause. In the more rapidly fibrosing cases, peripheral block occurs early, and this may prevent marked first stage appearances beyond those due to lymph block and dust cell collections, which will clear up to a certain extent when the peripheral block is complete. These are the only explanations we have to offer, as actual fibrosis will not disappear. Emphysema is always quite marked in this stage.

The black, macroscopic pigmentation seen in a sectioned silicotic lung is often associated, because of its distribution, with the spots in the roentgenogram. The pigment is in the areas of fibrosis, but has little or nothing to do with the shadows, which are due solely to fibrosis, except possibly in the case of metal dusts.

Diagnosis. The appearances of this stage are so characteristic that the condition is not likely to be confused with any others, except miliary tuberculosis, tuberculous bronchopneumonia and certain mycotic infections. We have examined one case of sporotrichosis in which the appearance was indistinguishable from that of a nodular type of pneumoconiosis and the final diagnosis was determined only at autopsy. The history and absence of fever and other constitutional evidences of miliary tuberculosis should render the diagnosis in this respect comparatively easy, except that in the late stages of silicosis which is about to terminate fatally, the clinical evidences of tuberculosis are closely simulated. The differentiation of a superimposed adult tuberculosis, with or without bronchopneumonia, is sometimes a more difficult problem than we are led to believe. At an early period in this type of pneumoconiosis, it may be differentiated readily, but later on, especially when the third stage is imminent or overlapping, the diagnosis becomes far more difficult. Møller,[81] in a recent article dealing extensively with differential diagnosis, calls attention to the great necessity for clear roentgenograms in order to see the delicate network pattern of fibrosed interlobular septa between the fibrotic spots in distinguishing silicosis from tuberculosis. While he mentions distinguishable differences between the nodule shadows and the tuberculous ones, he is dealing with potters only, and the differences in shadow appearances cannot always be applied in all pneumoconioses. The nodules and other evidences of fibrosis differ very materially in the various dusty industries. To one who is keenly alert to the detection of tuberculosis in one group of silicosis cases with which he is quite familiar, through constant study, especially serially, the differentiation is not so difficult. But should such a student of one group of cases be thrown in contact with an entirely different occupational group, the problem becomes more difficult, at least until he becomes fully oriented.

Most roentgenologists have had the experience of seeing one or more cases of

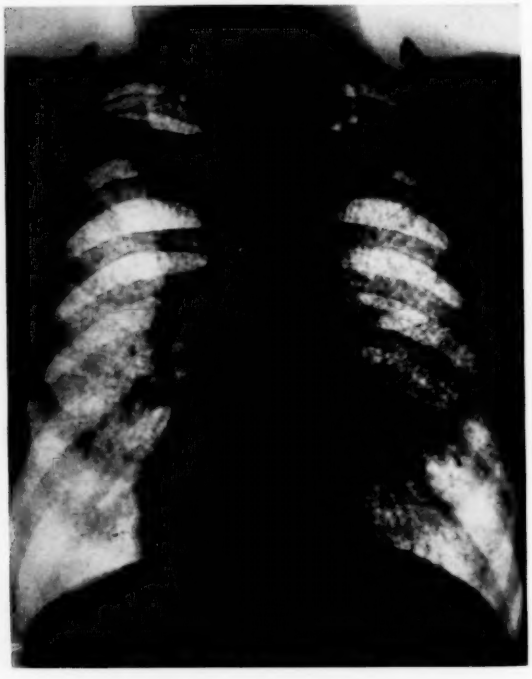


Fig. 5. Beginning coalescence of nodular fibrosis of the so-called second stage into larger masses of diffuse fibrosis of the terminal or third stage. This is more marked on the right side. There is a very definite haze between the nodules. Male, aged fifty-two, hard coal miner for thirty years.

multiple symmetrical lung calcifications, and most of us have regarded them as evidences of healed miliary tuberculosis, with or without good reason to so diagnose the condition. The appearance is not likely to be confused with silicosis. Sayers and Meriwether[99] have had the unusual experience of having found 125 such cases in an examination of 18,285 men at the Pilcher, Oklahoma, Mining Clinic. Many but not all of these men had been miners, and some of those who had been, showed real evidences of pneumoconiosis in addition. The lungs showed a diffuse distribution of dense, discrete, apparently calcified, shot-like spots throughout the lungs. They were of all sizes up to 1 cm. in diameter, and were variously ascribed to fungus infections, pneumomycosis and healed miliary tuberculosis.

Pathology. The fibrotic nodules have their incipiency in the lymphoid deposits. Some of these become larger and larger by aggregation of cells, their liberated dusts and subsequent fibrosis. They are the greatest primary centers of obstruction to lymphatic traffic outside of the pulmonary lymph nodes. Gardner[27] describes the fully developed nodule as consisting of a central mass of hyaline tissue surrounded by a capsule of young fibroblasts which is quite cellular. Between the cells are great numbers of dust phagocytes. The contraction of the central mass chokes off vessels and bronchioles within it. These nodules become larger by subsequent aggregations until they become entirely macroscopic.

The sharply defined nodules of workers in some high silica content dusts (abrasive tool grinders and quartz rock miners and some others) are probably the result of sharp limitation of the fibrosis. The softer and fuzzy nodules are more often found in those exposed to more slowly fibrosing dusts, as in coal miners, potters, cement workers, asbestos workers and a few others. These nodules require a longer time for development. This is not always the rule however.

Third Stage. This stage has been characterized by appearances due to a predominance of diffuse fibrosis, which may present three fairly definite and distinct appearances, although all of them may be observed in the same case:

(1) The larger nodules of the second stage, where most prevalent, either may coalesce into very much larger and irregular masses, or be found close together with more or less haze between them (Fig. 5). It may be difficult in such cases to differentiate between second and third stages except by a lack of expansion and diaphragmatic excursion, and the presence or absence of diaphragmatic irregularities.

(2) A more or less diffuse fibrosis, somewhat similar in appearance to the fibrotic process representing the late result of an extensive bilateral chronic pulmonary tuberculosis. Usually definite nodules are still present, although not always (Fig. 6).

(3) The presence of massive fibrotic

areas presenting the appearance of extensive pulmonary consolidations. In the late period of the stage there is usually one such area on each side, rather symmetrically located subapically, but sometimes unilateral, or more extensive on one side than the other (Fig. 7). In an earlier period of the stage, when small, they may appear quite asymmetrical. Lateral roentgenograms have shown us that many or most of these subapical masses are in the apices of the lower lobes, and numerous autopsy reports in the literature have confirmed this location. Often associated with these appearances dense fibrous bands are found extending in various directions, but prominently downward, and frequently causing marked diaphragmatic deformities. They often resemble thickened trunks. The heart and vessels are quite likely to be displaced when these bands are present. Diaphragmatic excursion is very much restricted or entirely absent.

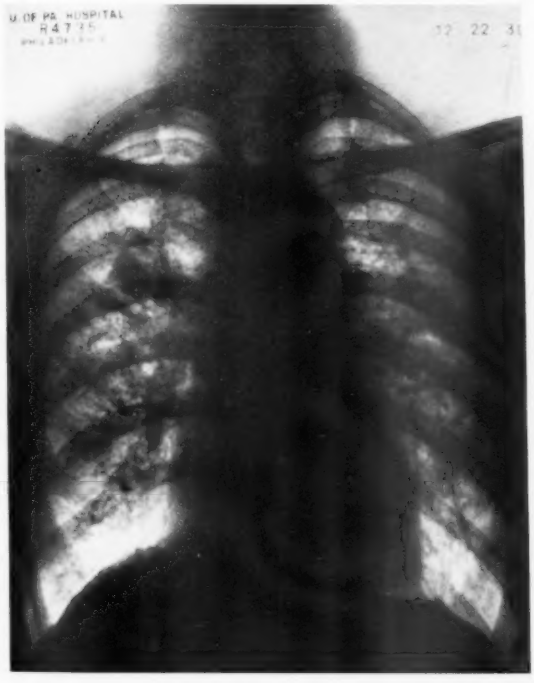


Fig. 6. Terminal diffuse fibrosis (third stage) which resembles the appearance often seen in chronic fibroid tuberculosis. Male, aged forty-nine, worked for fifteen years as a rock driller in a sulphur mine. This was eighteen or twenty years ago and he has not worked in a dusty occupation since. The condition has probably been progressive. Consolidations are beginning. There were few physical signs.

Fig. 7. Typical appearance of terminal fibrosis (third stage) with bilateral subapical massive consolidations. Male, aged forty-three, hard coal miner for eighteen years.

First stage changes are usually not apparent in the third stage.

Diagnosis. The difficulties in differential diagnosis of tuberculosis in this stage are obvious, especially as tuberculous pneumonias are common in third stage cases, and may closely resemble in their appearances the massive fibrotic areas, as may also primary tuberculous consolidations. Tuberculous pneumonic areas of various sizes may occur anywhere in the lungs in these cases. In reviewing with Dr. Russell[98] the roentgenograms collected from the Barre granite investigations, we were convinced of the fact that tuberculous pneumonias were common, that the lesions were clinically very often at the bases where roentgenographic conolidations of one condition or the other were apparent, and that their possible tuberculous identity was very frequently not suggested because no pri-

mary foci were distinguishable elsewhere. From the roentgenographic standpoint they would usually be interpreted as silicotic.

The roentgenogram alone does not easily differentiate a superimposed tuberculosis in association with the first type of diffuse fibrosis mentioned, except in the presence of cavitation. Serial studies and rapid changes due to tuberculous invasion will make the diagnosis far more obvious.

When the massive fibrotic areas are unilateral or larger on one side, they may be confused with primary lung cancer. When adjacent to the mediastinal shadows they often present the appearance of mediastinal tumors. Syphilis is a common intercurrent disease and may have associated lung lesions. (See unusual complications.) In all of these instances there certainly would be other evidences of silicosis elsewhere. The difficulty lies in detecting or differentiating these conditions when they are coincidental with silicosis.

Pathology. The first two appearances result from an aggregation and coalescence of the smaller nodular fibrotic areas of the second stage or an advance of the interstitial fibrosis, or both. The pathological identity of the areas of massive fibrosis is more or less problematical or in doubt. Investigators of considerable experience, notably Mavrogordato[70] and Watkins-Pitchford,[122] believe they are due to a combination of silicosis and tuberculosis, although their origin from a coalescence of nodules is regarded as possible. These areas seldom caseate, but when they do, bacilli are often found, but not otherwise. Other infective agents as well as tuberculosis have been regarded as possible contributing causes of these fibrotic areas. It is a well-recognized fact that tuberculous infection and silicosis working together produce far greater fibrosis than either alone. Gardner[29] has proved this by animal experimentation. These massive areas may be of the nature of chronic tuberculous atelectatic cirrhosis.

We have already called attention to the fact that in certain industries the silicotic appearances do not run true to type. The typical case would be one progressing through all three stages. This does not always occur. A notable example is to be found in the granite industry (Russell, Britten, Thompson and Bloomfield[98]), in which the typical nodular appearance of the second stage is so often lacking or inconspicuous. The first stage appearances if present are replaced by those of diffuse fibrosis, in which the areas of massive fibrosis may later develop. We have noted this lack of type progression occasionally in other industries, but its frequency and peculiarity to certain occupations are most forcibly shown by serial study.

Other Classifications. Attention was called at the beginning of this section to the clinical classifications of South Africa, which were legalized later. Roentgenological classifications naturally had to be made to conform to these. The present general classification of South Africa, modified from the one previously mentioned, has been given to us through the courtesy of Dr. G. C. Brink, and is as follows:

1. Rather more fibrosis than usual	
2. More fibrosis than usual	
3. More fibrosis full	
4. More fibrosis to commencing fibrosis	Ante primary
5. Commencing fibrosis	Ante primary
6. Commencing fibrosis plus	Ante primary
7. Commencing to early	Primary
8. Early commencing	Primary
9. Early to medium	Primary
10. Medium fibrosis	Secondary
11. Medium to advanced fibrosis	Secondary
12. Advanced fibrosis	Secondary

Complicated classifications are more apt to become popular in the examinations of individuals in a single industry than when several industries are studied, as seems to have been the case in connection with the South African gold miners, and as was the case with Jarvis[53,54,55] in his studies of the Barre granite cutters, referred to in our

previous communications. They are, no doubt, admirably adapted for use when practically the entire work of an individual or board is restricted to the examination of silicotic individuals, especially in one industry, but they are hardly practicable for roentgenologists in general, who are more favorable to simple classifications.

In the formulation of the most excellent Workmen's Compensation Act of Ontario, especially in respect to silicosis, the clinical classification of the South African Board has been embodied. This section of the Ontario Act reads as follows:

(9)—(a) "Silicosis" shall mean silicosis of the lungs (a fibroid condition of the lungs caused by the inhalation of silica dust).

(b) A person shall for the purpose of this Act be deemed to have or to have had silicosis,—

(I) In the ante-primary stage when it is found by the Board that the earliest detectable specific physical signs of silicosis are or have been present, whether or not capacity for work is or has been impaired by such silicosis;

(II) In the primary stage, when it is found by the Board that definite and specific physical signs of silicosis are or have been present, and that capacity for work is or has been impaired by that disease, though not seriously and permanently;

(III) In the secondary stage, when it is found by the Board that definite and specific physical signs of silicosis are or have been present, and that capacity for work is or has been seriously and permanently impaired by that disease, or when it is found by the Board that tuberculosis with silicosis is or has been present.

In discussing the comparison of stages recently with Dr. Brink, of Toronto, we agreed that the following one seemed logical: That the ante primary stage seems to correspond to our first stage; the primary, to an early but well-developed second stage; the secondary, to an advanced second or third stage. It should be borne in mind that these clinical stages do not depend entirely upon the roentgenographic appearances.

The 1925 South African law defines three legal stages of silicosis practically identical with the above Ontario specifications. In view of the greatly altered aspect of the disease in South Africa, it has become necessary to recognize additional *clinical* groups of cases, which Watkins-Pitchford[121] summarizes somewhat as follows:

(a) *Simple Silicosis*. The condition in an individual who remains free of overt tuberculosis. It is non-progressive and produces but little effect upon the health. From the pathological standpoint, these subjects present numerous small, inert nodules of dense fibrous tissue, symmetrically distributed. Each nodule is sharply defined from the surrounding tissue, and is so well encapsulated as to be easily shelled out. They vary in size from 3 to 4 millimeters and are rarely over 6 millimeters. If closely aggregated, they may produce a certain amount of disability, mainly shortness of breath. The roentgenological examination is more reliable than the clinical one.

(b) *Tuberculosis with Silicosis*. This is a progressive and serious disease associated with larger nodules unsymmetrically distributed and composed of young connective tissue elements among which tubercle bacilli are found. Adjacent nodules are frequently aggregated into masses. There are two classes of cases in this group: (1) The individual may have had simple silicosis at first, followed by the development of unsymmetrical tuberculous lesions (*tuberculo-silicosis*). This change may occur after many years. (2) The tuberculous lesions may be manifest first, followed by the silicotic ones in close association (*silico-tuberculosis*). Here again, the roentgenographic findings are important. In tuberculo-silicosis, the hitherto uniformly mottled areas are now invaded by one or more unsymmetrical areas of shadow with mottling around them. The Miners' Phthisis Act now provides separately for these two

general groups of cases, as has been the case in Ontario more recently.

We must be careful not to confuse the Rand conditions with our own occupations because of the great tuberculosis problem in South Africa.

It is interesting, but somewhat surprising, to note that there has been no material change in the general classification of late in South Africa. At the meeting of the First International Conference on Silicosis[11] at Johannesburg, in August, 1930, the three clinical stages recognized locally were accepted by the Conference. They were as follows: *First Stage*—Respiratory symptoms slight, few or no physical signs and capacity for work little impaired. Roentgenograms show the linear shadows increased and present discrete shadows of nodulation. *Second Stage*—All physical signs are increased. The nodular shadows are increased in number and size and show a tendency toward confluence. *Third Stage*—All signs and symptoms are greatly accentuated, and there is a total loss of working capacity. When tuberculosis is present, the stage classification must be based more or less upon a loss of working capacity than upon physical signs and roentgenographic appearances. It was recommended that an internationally comparable roentgenographic technique and terminology be adopted, and that a further study be made of the correlation of roentgen appearances, pathology and symptomatology of silicosis with or without tuberculosis. Personally we would regard this as impossible with the above classification.

In the light of our more recent experience with pneumoconiosis affecting workers in various industries, it seems more rational to dispense with any attempts to employ general stages of progression in any of the ways so far discussed and to substitute a pathologic-roentgenological classification which may be combined or fit in with the clinical aspect peculiar to any one industry, or all of them.

Those who have studied a single phase of pneumoconiosis in one occupational group, such as asbestos workers, cement workers, coal and hard rock miners, granite cutters and sand pulverizers, for example, have found it most difficult to apply any definite numerical order of progression by stages that is used for other occupations. Likewise, those of us who study a large number of occupations and industries find it difficult to adhere to such a general division into stages which had their origin in the study of hard rock miners, without making exceptions or creating certain variants. This has become more and more difficult as various new occupations are studied. Pneumoconiosis implies a condition of fibrosis which can occur, so far as we know, in only one general way, but with certain variations dependent upon uncertain or unknown influences.

Now the clinical phenomena must, of necessity, depend upon certain forms of pathological changes. Furthermore, roentgenographic appearances portray these pathological changes as soon as they become macroscopic, or reveal their influences while the actual changes are still microscopic. Therefore, it would seem better to substitute for a numerical progression of pathological changes typical for a few of the occupations a general pathological classification which will include the typical and the variants, and at the same time be applicable to both clinical and roentgenological studies for each individual industry or occupation. Such an attempt cannot be carried out successfully by any one individual or group, but must receive universal recognition as to its value and applicability. We offer a possible plan for thought and discussion, and in the meantime we are trying it out.

The study of a diagrammatic representation of the lymphatic system of the lungs, such as that of Miller[76,78] (Fig. 8) and an application of the pathological features of the condition to this will show that there are practically three simltaneous primary distributions or accumulation points for dust which correspond to later possible manifestations of fibrosis. These may be sum-

marized as follows: (1) through the peribronchial and perivascular lymphatics, which, through blockage of these systems, may later on cause the intensification of trunk shadows, linear markings and pulmonary lymph nodes; (2) lodgment in lymphoid deposits with subsequent development of nodular fibrosis; (3) a thoroughly interstitial fibrosis following a rapid block of lymphatic channels. To these, of course, would be added the pleural side-track which is more or less common to all cases and needs no special classification.

From a study of various industries, it seems evident that fibrosis may exhibit *predominance* in any one of these distributions in individual occupations. For example, in coal mining the driller shows predominance of the nodular type, whereas the man in the breaker may exhibit only the first for many years; in hard rock mining the nodular type predominates until diffuse fibrosis supervenes; in the granite cutter the interstitial type predominates, although the nodular may exceptionally do so; in the asbestos worker the interstitial type is characteristically predominant. Interstitial predominance, rapidly progressing, will develop into diffuse fibrosis without nodular predominance. And so we might run through all the fibrosis producing dusty occupations. The following pathologic-roentgenological classification is offered as a suggestion to overcome the existing confusion:

1. Peribronchial-perivascular-lymph node predominance { rapid / slow
2. Early interstitial predominance (Interferes with diaphragmatic movement) { with nodular appearance / without nodular appearance / rapid or slow
3. Late or advanced interstitial predominance
4. Nodular predominance { non-progressive / progressive
5. Advanced diffuse or terminal fibrosis { conglomerate nodular type / interstitial type / massive fibrosis type

It is obvious that many individuals may show or occupations be characterized by various combinations of these types, but usually, in one industry or occupation, there will be a sequence of predominant appearances which will correspond closely to the clinical aspect and progression of the disease if all data are properly correlated.

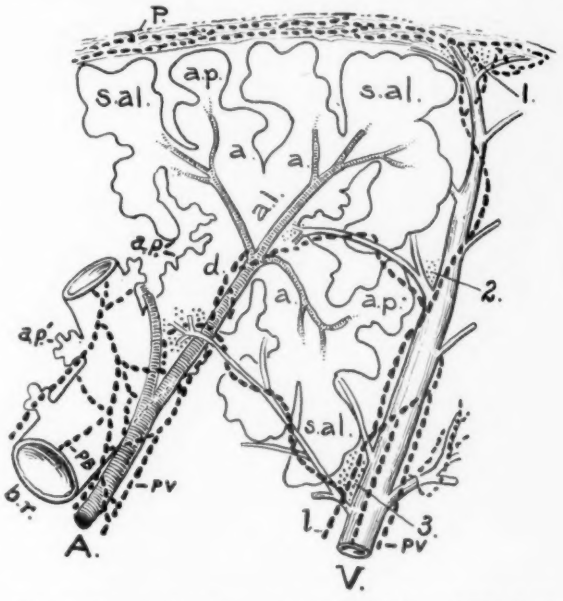


Fig. 8. Composite diagram (modified from Miller) of the primary lobule lymphatic system of the lung, indicating the primary distributions or accumulation points for dust which may correspond later to predominant types of fibrosis. br, respiratory bronchiole; d.al, alveolar ducts; a, atria; s.al, sacculi alveolares; a. p, alveoli; a. p^1, alveoli opening into respiratory bronchioles and alveolar ducts in close relation with the origins of peribronchial and perivascular lymphatics; A, branch of pulmonary artery; V, branch of pulmonary vein in interlobular septum; P.B, peribronchial lymphatics; P.V, perivascular lymphatics; 1, 2, 3, lymphoid deposits. (By permission of Dr. W. S. Miller.)

We have found it difficult to understand or to explain all of the underlying factors in what seems to be a rapidly developing

interstitial fibrosis, but Gardner[27] has largely supplied the missing link. He states that the obstruction in the deep pulmonary lymphatics diverts the lymph flow and dust cells toward the pleura, but counter-resistance is met there. Consequently dust cells pass through the walls of the lymph vessels and accumulate in the surrounding connective tissue at a point where the two lymphatic systems communicate. He offers in support of the theory first advanced by Watt, Irvine, Johnson and Stewart[123] of the choking of lymphatic channels by dust cells and the contraction of their lumen, which has been open to criticism, that the point of actual obstruction could be in the pulmonary lymph nodes, which would produce stasis in both deep and superficial lymphatics. He further suggests that the previous condition of these lymph nodes as to changes induced by childhood tuberculosis and other agencies might have some influence on the rapidity of onset and progression of silicosis.

PREVENTIVE MEASURES

Roentgenologists of this country are not particularly concerned with the details of the various preventive measures, aside from a general idea of the methods employed and a humanitarian interest in the results obtained.

The greatest danger to the workers, aside from the harmful dust itself, lies in the prolonged suspension of the smaller and dangerous-sized particles in the atmosphere. It has been computed that twenty minutes are required for particles of 5 microns in diameter to fall 6 feet, and eight hours for those of 1 micron in diameter to settle the same distance in a quiet atmosphere.[80]

It will be obvious, from the foregoing remarks, that six very important procedures in protection are necessary: (1) To keep the dust particles produced down to a minimum quantity in the atmosphere to be inhaled; (2) to allow the dust to settle as much as possible before it can be inhaled; (3) to rapidly remove the dust-laden atmosphere instead of allowing it to remain stagnant; (4) to separate the particles from the air before they can gain entrance to the respiratory tract; (5) to prevent the spread of tuberculosis; (6) to appoint satisfactory medical boards for control of the condition.

(1) Dry drilling is the first great danger in mining and quarrying, and the use of the pneumatic tool in granite and sandstone dressing is equally dangerous. Even in coal mining, the driller has a more or less continuous occupation in going from place to place to drill through the rock faults. Dry drilling is prohibited by law in many countries, notably South Africa. The axial water feed drill is now in general use there. Hay[40] has described a device whereby the exhaust from the rock drill creates a negative pressure in a tube coming from a rubber bag around the drill where the latter enters the drill hole in the rock. This tube extends into a flannel bag above a dust container. The suction draws the dust away from the rubber bag around the drill and forces it into the flannel bag. The principle is similar to that of the household vacuum cleaner. Machines which produce large dense clouds of dust should be supplied with exhaust devices, whenever possible, to take away the dust laden air coming from them, and especially when the employees are working in enclosures. This means of protection is now receiving a great amount of attention in connection with the asbestos industry. The use of abrasive instruments or devices and sand blasting require similar protection.

Mavrogordato[71] describes two classes of dusts, as follows: (1) "income dust," or that made from day to day, and (2) "capital dust," or that which is always present and either circulating in the air or easily stirred up. Each must receive individual attention from preventive measures.

Spraying has been a popular measure for the purposes of keeping down dust which has already settled, or of hastening the settling of that in the air by surrounding the particles by those of the fine aqueous spray. Mavrogordato[71] has advised against water spraying because experiments carried out

by him have shown that water droplets in the air facilitate the entrance of dust particles into the lungs. While the use of water reduces the amount of air borne dust, that remaining is more dangerous than it would be in the dry air. He recommends the dry methods if they can be carried out. Cluver[11] states that at the first International Conference on Silicosis in 1930, wetting and spraying were regarded as futile.

Wetting is a safeguard in sandstone grindstone abrasive work, but when the water dries out, the fine dust is left wherever it has settled.

Cleanliness is often a factor in safety, as in the pottery industry.

(2) Enormous quantities of dust are stirred up or liberated by blasting. It has been recommended that blasting be restricted in time to the ends of shifts, and that workers do not go into the area of the blast until a sufficiently long period has elapsed for the dust to settle or to be partially exhausted.

(3) One of the greatest safety measures is satisfactory ventilation, when it can be carried out. This consists of two procedures —exhausting the dust laden air and replacing it with new fresh air.

(4) The direct removal of dust particles from the atmosphere before they can be inhaled is accomplished through the use of filters or masks, or both. Katz, Smith and Meiter,[58] who have fully described the types of both, conclude that the use of respirators should be encouraged, but that they are not a final safeguard. Barreto, Drinker, Finn and Thomson,[3] in a description of many devices, conclude that the most efficient filters must be composed of a dense filtering material. This necessitates a large surface in order to lower the resistance to breathing. The most efficient ones are of the bag principle, the reverse of the vacuum cleaner. From these large filtering devices, a large caliber tube usually leads to the mask worn over the face. The entire equipment is hot, uncomfortable and expensive. All such filters should be "plugged" before using with finely divided fume particles, such as the oxides of zinc, magnesium or aluminum in order to make them more efficient. Belt[4] states that Bulmer of the Ontario Department of Health has devised a compressed air respirator which supplies fresh air directly for respiration.

(5) Measures directed toward the prevention of the spread of tuberculosis comprise the non-employment in silica dust industries of any tuberculous individuals or suspects and the immediate elimination, for his own and the safety of his coworkers of individuals who develop the disease while employed.

(6) Satisfactory prevention of the disease requires the appointment of special medical boards, with full power to act, such as have been established in South Africa and elsewhere.

Results of Protective Measures. The dusty occupations are an absolute necessity to our civilization. They are, in a measure, a necessary evil, but the evil may be reduced to a minimum, as has been proved by the results of preventive measures. This must be accomplished through legalized health regulations, but wherever compensation laws have been provided, the two seem to work well hand in hand.

In 1923, the Transvaal was supplying over 50 per cent of the world's output of gold, according to Watkins-Pitchford.[121] Between 1911 and 1923 the Rand mines produced an annual average of 35,000,000 pounds sterling in gold, hence legislative bodies could not overlook the necessity for compensation and protection for workers engaged in the production of so much wealth. Since the operation of the Miners' Phthisis Bureau and the adoption of protective measures, the character of "miners' phthisis" has changed remarkably. This is further confirmed in the report of the Miners' Phthisis Medical Bureau of 1927.[79] Silicosis is being brought more and more successfully under control except in the case of drillers, and the old type of the condition characterized by extensive fibroid consolidations, in which the factor of silica dust was predominant, has given place to a

new type in which the tuberculous factor is uppermost in importance. In other words, they are now combatting an endemic outbreak of tuberculosis among the native African miners.

Watkins-Pitchford[121] regards silicosis as a preventable disease just as railroad accidents can be minimized, but the results of negligence are not recognizable at once, but only after several years.

Irvine[52] states that since medical examinations have been in force in South Africa, and the miners have been examined routinely, there has been a decrease of from 3.64 per cent to 1 per cent in the development of silicosis among miners after ten years of labor. This has been brought about despite the fact that these men have been working in rock containing 86 to 96 per cent of silica. Watkins-Pitchford[121] states that the shortest time now under ground to the appearance of the first signs of silicosis is four and a quarter years, and an average of ten and a quarter years, which is much longer than formerly.

One should not gain the impression that nothing is being done in this country to overcome the evils of pneumoconiosis. Federal, state and municipal health bodies are keenly alive to their importance, and have collected many valuable data for reference.

Remarks on Special Industries

This presentation is in the nature of a review of certain aspects of the subject of pneumoconiosis. We have included in it our own experiences, especially so far as they may be new since our previous contributions. Our interest in the subject has afforded the opportunities of examining many hundreds of roentgenograms in consultation, but as most of these have been reported by other authors, we do not include them in our own statistics without special mention of their origin.

Many of the dusty industries present certain unusual or interesting features which cannot be brought out satisfactorily in a general review of the subject, hence it has seemed wise to discuss each one of these separately.

Coal Mining. This is one of the most interesting of the very dusty occupations, largely because we have to deal with two distinct kinds of dust. Moreover, there are probably more men engaged in this industry than in any other one mining work. Like many other industries, this one provides many different occupations which expose the workers to widely different quantities of any injurious dust. In both anthracite and bituminous coal mining enormous amounts of coal dust are inhaled by all of the men inside the mines and by those working outside in the anthracite breakers. In addition, many of the men employed in a coal mine are engaged in quite a different occupation. We refer to those who use the jack hammer in drilling, especially into solid rock. Tattersall[115] explains in a very brief manner how these men are so much exposed to silica dust in the Welsh mines. They are called upon for intensive drilling whenever a fault or rocky break is encountered in a seam of coal. These faults usually contain a fairly high percentage of silica. The drillers are called from place to place in the mines as their services are required, and their work is almost a constant one.

It has been our experience that there is a difference in the frequency, incidence and severity of the pneumoconiosis acquired in the hard and soft coal mines. It is our impression, gained from the interpretation of many hundreds of roentgenograms of men working in both kinds of mines, that the incidence is somewhat earlier, the progression a little more rapid and the terminal diffuse fibrosis changes more frequently found in anthracite than in soft coal miners. Nevertheless, the U. S. Public Health Bulletin No. 187[27] states that in the soft coal mine investigations the coal dust contained 1.2 per cent of free silica and the rock dust 54 per cent, whereas in hard coal mining the figures were 1.5 and 31 per cent respectively. It may be that hard coal mining has more dust associated with it. The character of the rock plays an important

part in all of these features. One of the worst cases of silicosis we have ever seen was in a hard coal miner of thirty years' occupation.

The drillers and their helpers invariably present the worst features of the disease. By knowing the approximate time of occupation, one can usually select from a group of roentgenograms those of the men who were engaged in this part of the work. They present at different periods all of the three characteristic stages of the ordinary types of silicosis, and the appearances do not differ to any extent from those of men working in other hard rock mining industries. The incidence is probably a slightly longer period of time and the progression somewhat slower in comparison with hard rock miners in general. Edling,[22] in an examination of 46 coal miners of southern Sweden, without knowledge of clinical data, found that the average duration of work by those showing the first stage changes was fifteen years; second stage changes, thirty years and the third stage appearances, forty-one years. Coexistent tuberculosis was diagnosed positively in only one case.

It is generally conceded that coal dust, per se, is relatively innocuous, at least as compared to silica and asbestos, but that it does produce a mild fibrosis of the lungs. Appearances of pneumoconiosis are found to a slight extent among the anthracite breaker workers, but no one would look upon this dust as definitely harmful. We have found fairly well established nodular fibrotic appearances in roentgenograms of the chests of locomotive firemen and ship stokers. These men worked with soft coal. Collis and Gilchrist,[14] on examining the chests of coal trimmers at the Cardiff docks, found roentgenographic evidences of mild pneumoconiosis in many instances.

Other forms of carbonaceous material than coal may give rise to mild fibrosis of the lungs. Hollmann[51a] examined a large number of workers in a pencil factory who were exposed to carbon or graphite dust. Those working up to five years showed no evidences of pneumoconiosis, but 9.1 per cent of those working over that period did show some fibrosis. He concludes that graphite dust acts in about the same way as pure coal dust.

Arnould[1] thinks that anthracosis as such is not a condition at all, and should be eliminated from the list of dust diseases and especially as an occupational disease. This might apply to coal handlers but certainly does not to miners, many of whom do acquire actual silicosis. It is difficult to separate the two groups among miners because all of those working in the mines are exposed more or less to both kinds of dust. It is perfectly true that pure anthracosis is not a dangerous or crippling condition, but when a miner presents evidences of very definite fibrosis within a period as long as twenty to thirty years we know he is silicotic. It is not necessary to discard the term if we are careful in our interpretations. We must be fair, however, to both employers and employees in differentiating conditions which are practically harmless from those which are harmful or eventually incapacitating.

Coal dust is taken up and distributed through the lymphatic system by dust cells or macrophages in the same manner as is silica, but the effect upon these cells may be quite different. Collis and Gilchrist[14] quote Haldane and others as stating that coal dust is picked up from the alveoli by the macrophages more readily than most any other dusts.

Some authors suggest that the mild action of coal dust may, under certain circumstances, *enhance* the effect of silica. Cummins[20] made pathological studies of one of the coal miners included in Tattersall's article.[115] This man was exposed to silica dust for four years before becoming a coal miner at the face. He afterwards died. No tubercle bacilli were found during life or at autopsy. The lungs contained only 1.4 per cent of silica in the ash comprising 10 per cent of the lung. Normal lung gives approximately only 3.2 per cent of ash. The lungs showed very definite fibrosis and a great accumulation of coal dust pigment.

Many coal dust bearing macrophages were seen and others were disintegrated and had left their coal burdens behind. It was suggested that the lungs were first damaged by silica fibrosis and the lymph drainage was crippled. Subsequently, the coal dust became entangled by the fibrosis from the silica, whereas it would have been allowed to go on or be eliminated by a non-fibrotic lung. The supposed result was that the usually harmless coal dust so accumulated that it accentuated the preexisting fibrosis sufficiently to cause death. Middleton[74] throws a somewhat different light on the subject by dealing with it under slightly varied circumstances, and those under which the drillers really are found. He says that among men employed in the hard headings to reach coal seams, it is likely that in the more acute silicosis cases the coal dust aids the silica dust in producing the fibrosis after lymph block has resulted from the silica.

These hypotheses must not be confused with the rather prevalent views that coal dust retards the fibrosing tendencies of silica when both dusts are inhaled simultaneously, but silica does not predominate to such a great extent as to cause rapid fibrosis. For example, Mavrogordato[71] believes that coal dust interferes with the usual action of silica dust. He also believed[70] that the former caused the dust cells to die more readily, that they were digested easily and left their coal dust burdens in situ. Heffernan and Green[44] and Heffernan[42] have explained this retarding action of coal dust on the production of silicosis by the fact that the formation of silica sol is retarded by it or that the hydrated colloidal silica is coagulated by it so that the activity of the silica subsides and it becomes inert. (See pathology.)

We therefore seem to have authority for two actions of coal dust—it retards the action of silica when there is a slow intake of the latter, and it enhances its action when the intake of silica is rapid. These views might be made to conform with the findings among coal miners of a comparatively few cases of extreme silicosis among a relatively large number of very mild cases.

Another very interesting feature of anthracosis is the alleged protection directly or indirectly afforded by the coal dust against tuberculosis. There seems to be a considerable difference of opinion as to whether or not this is an actual fact, and the controversy is still active. Probably it should be narrowed down to the two questions—first, as to whether or not the coal miner is predisposed to tuberculosis through his exposure to dust, and, secondly, if not so predisposed, does the coal dust afford him any protection against the development of the infection?

Schlossmann[100] injected a suspension of soot in oil intravenously into animals and produced anthracosis of the lungs. Tuberculosis was not influenced unfavorably thereby. Henius and Richert[45] inoculated rabbits with tuberculosis and simultaneously gave inhalations of coal dust. After three months the inhalations did not induce the development of connective tissue in the tuberculous lungs. The coal dust was well distributed in the interstitial tissues, and often there was a more pronounced accumulation of dust around the tuberculous foci. The dust had apparently no effect upon the type of tuberculosis. Three months seems like a very short latent period. Wedekind,[124] in a series of experiments on rabbits, succeeded in inducing the healing of tuberculosis of a fatal type by the intravenous injections of a suspension of coal dust. It was supposed that the irritation of the cells of the vascular endothelium by the coal dust particles caused the migration of large numbers of phagocytes into the lung tissue.

Collis and Gilchrist[14] voice the general opinion that tuberculosis mortality is low among coal miners, but they state that in certain British coal fields, especially in Lancashire and South Wales, there is an unusually high death rate from respiratory diseases such as pneumonia and bronchitis. They also believe that silica is the only dust that predisposes to tuberculosis. They

give statistical evidence to show that the coal trimmers at the Cardiff docks who had been exposed to almost pure coal dust for a number of years and did show mild changes of pneumoconiosis had a somewhat lower tuberculosis mortality than is the standard among other men in general.

In our previous communications there were numerous references with statements for or against the protecting influence of coal, mostly the former.

Mavrogordato[71] states that coal dust, per se, does not seem to influence resistance for or against tuberculosis. This is probably the correct general status of the question. No doubt the comparatively infrequent cases of rapidly progressing silicosis among the coal miners have been more or less predisposed to tuberculosis, but the coal dust does no harm in the mild cases of anthracosis.

If there is any protection in the industry, it probably arises from other factors. The important ones, at least in one district, are well embodied in an old paper by Wainwright and Nichols,[120] in 1905. In seeking a cause for the supposed protection against tuberculosis in the anthracite regions of Pennsylvania, they finally concluded that it was an actual fact, probably due to several factors. As contributing ones they suggested the following: The absence of crowding at work; lack of extreme overcrowding in housing; the custom of these miners in walking or riding considerable distances; the forced daily bath because of the black dust accumulated on the body each day; the moisture of the mines preventing sputum from drying and the gradual bacterial purification of the air from mine entrances to the working chambers. Animal experimentation suggested that the coal dust offered some protecting influence against tuberculosis through the stimulation of a mild fibrosis, which they thought was the essential factor, but coal dust had no direct bactericidal action.

The Asbestos Industry. This industry probably has received more attention of late than any other, partly because it has grown so extensively during the past twenty years as a result of the many commercial, industrial and household uses of asbestos owing to its resistance to heat and acids and its insulating properties against electricity and heat. This has caused attention to be centered around it as a factor in industrial disease, mainly, however, because of some very unusual features found in the lungs of those exposed to the inhalation of the dust. The first important one is the fact that pneumoconiosis is produced in the workers apparently by silicates instead of directly by silica. This fact will, no doubt, lead to further interesting studies of industries in which silicates predominate in the dusts. There is the utmost confusion in regard to the action of silicates in the production of pneumoconiosis, especially as certain of them like clay and kaolin are supposed by some authorities to retard the action of silica. In addition to these, talc, French chalk, soap stone, pumice and many other silicate substances are extensively used in various industries. Another unusual feature of pneumoconiosis in asbestos workers is, first, the ante-mortem and autopsy finding in the lungs of some very interesting, unusual and characteristic mineral deposits, and still another is a progression of fibrosis and roentgenographic appearances differing from those of most injurious dust producing industries. Numerous articles have appeared on the subject during the past four years. The most comprehensive one has been that of Merewether and Price,[73] supplemented by Merewether,[72] in 1930, in their general review of all phases of the asbestos industry in Great Britain and a résumé of the results of their examinations of 363 asbestos workers. Prior to 1928, there were available records in medical literature of only two deaths among employees in the factories, but since then, a considerable number have been reported.

The importance of the condition and its differences from other forms of pneumoconiosis seem to warrant a general acceptance of the term "asbestosis." The wide discussion of the subject of pulmonary as-

bestosis is ample reason for the presentation of a general résumé of the entire industry, as well as the pathological, clinical and roentgenological aspects of the condition.

The dust evolved at the asbestos mines contains a moderate amount of silica. The harmful products of the asbestos factories are almost entirely silicates. Heffernan[42] believes that silicates such as asbestos undergo changes in the lungs quite like silica, only slower, and that asbestosis is a true silicosis. This is, of course, not proved.

The product was mined and the asbestos fibers were separated from the mineral and employed in the making of indestructable fabrics several centuries B.C. Attention is called by Cooke[17] to a cremation cloth described by Herodotus 450 B.C. Materials made of it have been used ever since then, but the most rapid development of the commercial industry has been during the past two or three decades.

Nature. Asbestos is a peculiar fibrous and crystalline mineral composed almost entirely of silicates, mainly of hydrate magnesium silicate, with varying admixtures of those of aluminum and iron. The general term is applied to all silicate minerals which have a fine fibrous structure that can be split up into long, flexible fibers for the purposes of spinning and weaving. The fibers will split up in a longitudinal direction almost indefinitely. The minerals differ in their exact constituency, especially as to the amount of iron and aluminum, in different countries in which they are found and mined. Much of the asbestos used in Great Britain and the United States is mined in Canada. Cooke[17] gives the following chemical composition of asbestos:

	per cent
Silica	40.87
Magnesia	41.50
Iron oxide	2.81
Aluminum	0.70
Water	13.55

The Industry. At the mines, the mineral is blasted, crushed and finely ground in machines. The crushed dust is then passed over vibrating machines. The heavier rock particles are separated by gravity and the asbestos fibers are aspirated out by vacuum fans into special chambers. The crude asbestos is then shipped to the various factories. All of these procedures are carried out at the mine bases because of the economy in shipment of the lesser bulk of the crude asbestos.

The mining part of the industry is attended by the elimination of a large quantity of dust, which contains silica as well as silicates. Pneumoconiosis is found among the workers. Very little has been written about the condition of these men. Recently we have had the opportunity of examining the roentgenograms of 58 men from one of the Canadian mines, some of which showed pneumoconiosis. As the mineral rock contains as high as 60 per cent silica, the mine worker's condition is due largely to this directly, although probably not entirely. The raw product which goes to the factories contains very little free silica.

The most dusty occupations in the industry are to be found in the factories, in which the work is done in inclosures where the asbestos is refined and is finally spun and woven into the various materials with which we are familiar. During all of the factory processes, a large quantity of fine dust is set free, but in varying amounts in the different ones. Most factories, at least in Great Britain, have devices for removing much of the dust.

Early Case Reports. The first report of a death resulting from asbestos dust inhalation was presented by Murray,[83] in 1900. The man worked in a factory for ten years, mostly as a carder, and was the sole survivor, before his death, of 10 other men who started work with him. The autopsy on this case revealed pulmonary fibrosis. Photomicrographs of sections of the lungs showed large spicules of asbestos, at least they were so regarded at that time.

The second case reported in medical literature was presented by Cooke,[16] in 1924. It was again reported by him in detail in 1927.[17] This individual stopped his

work in a factory after eighteen years of intermittent occupation. The cause of death was probably asbestosis and superimposed tuberculosis. We referred to this case in our previous contribution,[91] in 1926, as largely a tuberculous one, especially as it was the first available autopsy report in the literature. In view of the many deaths which have been reported since then, we must now concede that this death was probably the result of both conditions. Naturally, Cooke was the first to describe the unusual and characteristic asbestos bodies in the lungs, and the authoritative description of them was made in his second report of this case in 1927. These bodies will be described in detail later on.

The second paper and third public report was presented by Oliver,[87] in 1927. He reported the cases of two women who had died as a result of asbestosis after working thirty and eighteen years respectively. Neither individual had evidence of tuberculosis. It is interesting to note that the second of these cases stopped work after eighteen years' occupation, and did not develop definite symptoms until four years later.

The next report was by McDonald,[68] in 1927. He referred more fully to Cooke's case, and reported an additional one which died. He thought it reasonable to believe that in the former one the tuberculosis was a superadded infection. His own case did not have tuberculosis. In addition to the two types of asbestos bodies first described by Cooke, he added a third, all three of which are now recognized.

Seiler,[101] in 1928, reported another case who had worked twenty-two years in various capacities in asbestos factories, and presented the typical symptoms of the advanced case. No tubercle bacilli were found in the sputum. The roentgenographic appearances seemed not to have been unusual.

Simson,[103] in 1928, reported two deaths among asbestos mill workers in South Africa, with autopsy findings. The first man worked only one year and died of miliary tuberculosis. The lungs showed slight fibrosis in addition to the evidences of the tuberculosis. The second case worked two years in the mill and died. The physical signs suggested tuberculosis with fibrosis. Autopsy showed a moderate degree of fibrosis with nodules, but quite cellular, and not like the usual silicotic nodules. There was no evidence of tuberculosis. The various asbestos bodies were found in both cases. These cases are of interest first, because both presented definite evidences of asbestosis after one and two years' work respectively, and also the various bodies characteristic of the disease, and, secondly, for the reason that the second case presented the terminal symptoms and died of the condition after only two years' occupation.

Wood and Page,[130] in 1929, reported autopsy findings in the case of a woman who died of bronchopneumonia after nine years' work in a factory. There were no evidences of tuberculosis. The lungs showed diffuse fibrosis and thickened pleura. Numerous asbestos bodies were found in the lungs, but not elsewhere in the body. Wood and Gloyne,[129] in 1930, reported the autopsied cases up to four. Tuberculosis was found in three of these cases, and in two, bacilli had been found in the sputum before death. Haddow,[36] in 1929, reported on the deaths of Oliver's two cases, and on two others. He stated that the certificate of the last one, March, 1928, brought about the publicity and official recognition of the condition. Since then, the workmen's compensation act of Great Britain has been extended to include asbestosis.[93] Haddow states that one of Oliver's patients had tubercle bacilli in the sputum.

Simson[103] quotes Hoffman[48] as reporting 13 deaths in 1918 and Collis,[12] 5 deaths in 1910. These were in health reports, and will be referred to again under predisposition to tuberculosis.

Mereweather and Price,[73] in their recent comprehensive report on the asbestos industry state that approximately 2,200 individuals are exposed to practically pure asbestos dust in the factories of Great

Britain. These authors examined 363 individuals among the workers. Of this number, 230 had been employed less than ten years, and only 21 over twenty years. All but one of the 363 individuals had been working at the time of the examinations. Ninety-five, or 26.2 per cent, showed definite evidences of fibrosis, due apparently to asbestos dust solely. Their table of the time incidence of the condition is of interest:

Years at Work	Cases Examined	Showing Fibrosis	Per Cent
0 to 4	89	0	0.0
5 to 9	141	36	25.5
10 to 14	84	27	32.1
15 to 19	28	15	53.6
20 and over	21	17	80.9

This table does not apply to any one group of workers in the factories. The authors have collected also, outside of these statistical cases, records of 10 deaths resulting from asbestosis, 9 of which were verified by autopsy and the tenth by repeated clinical and roentgenographic examinations. Nine of these deaths occurred from 1927 to 1929. The exposure of the 10 cases varied from nine to twenty-four years.

At the time of this writing, Lynch and Smith[67] (1930) are among the latest extensive contributors to the subject, and their report has been the first one in this country, at least in medical literature, to deal specifically with the subject. One of their cases, a negro, died as a result of a gunshot injury after working twenty-eight months in a mill during a period of three years. His lungs showed definite interlobular, perivascular and peribronchial fibrosis, and also the various asbestos bodies. The second case, also a negro, died of lobar pneumonia after four and a half years of continuous work in a mill. His lungs showed everywhere a definite increase of young fibrous tissue, in addition to the various asbestos bodies. Reference will be made to other cases examined by these authors in the description of asbestos bodies. It is interesting to compare the findings in these cases and those of Simson with the clinical table of Merewether and Price. It is quite possible that protective measures played an important part in the incidence of the condition, as shown in the report of the last named authors.

Appearance of Asbestos Dust. Cooke[17,18] has described the microscopic appearance of the components of asbestos dust in somewhat the following manner:

(1) Small fragments of asbestos fiber. The bulk of the fiber is translucent and glistening, with here and there within it opaque particles and minute black granules. These appear to be actually parts of the fiber, but their appearance suggests different chemical composition and physical characteristics.

(2) Translucent spicules split off from the fibers.

(3) Black, brown and blue particulate matter. The black particles are iron. They are few in the finished asbestos product but are numerous in the dusts of the carding rooms. The iron in the finished product was only 0.1 per cent, whereas in the dust of the carding rooms it was 18.4 per cent.

Asbestos Bodies. This is, perhaps, the most interesting feature of pulmonary asbestosis. The various bodies found in the lungs of asbestos workers have been described in detail by numerous authors, notably by Cooke,[16,17,18] McDonald,[68] Simson,[103] Gloyne,[30] Merewether and Price[73] and Lynch and Smith.[67] The description given by Cooke[18] of the various asbestos bodies is as comprehensive as that of any other author and is abstracted as follows:

(1) Enormous amounts of fine granular pigment like that seen in the asbestos dust fiber. Much of this may be carbonaceous.

(2) Large or moderate sized angular particles, 10 to 360 microns in size, corresponding to the black, brown and blue particulate matter found in the dust. These particles are found in fibrous and necrotic areas, singly or in clumps. Because of their size, they might occlude small bronchi.

(3) Almost complete absence of the very

fine, transparent or translucent spicules of fibers found so plentifully in the dust.

(4) The "curious bodies" so characteristic of pulmonary asbestosis. These are found in the alveoli and bronchioles and in the fibrous and necrotic areas. They measure 20 to 100 microns in length. One or both ends are bulbous, giving a clubbed or dumb bell appearance. The shafts are either homogeneous or segmented cross wise. They are golden yellow to brownish in color. They do not stain, but give a Prussian blue reaction for iron. The Bragg x-ray spectroscope showed that they were not altered asbestos fibers. Most of them are soluble in strong acids and alkalies, and Cooke, McDonald and Gloyne have been able, by this means to identify a slender mineral core derived from the asbestos fiber. Lynch and Smith were able to see this core as a central filament with slightly greenish tinge. These bodies are not essentially iron, but contain it. They are not found in the lungs of iron workers (Simson).

There have been various theories propounded as to the identity and process of formation of these curious bodies. McDonald[68] suggested that the asbestos fiber composed of magnesium silicate with a little iron had the magnesium separated out of it, leaving silica. The surface portion of this then passed into a colloidal state, at first a sol form, and remained associated with the asbestos fiber by adsorption and held there until it passed into a gel form. Eventually the entire mass might be converted into a gel. Simson[103] suggested that they represented particles of ferruginous quartz formed in the lungs under conditions similar to weathering or changed in composition as a result of combinations with constituents of the body fluids. Phagocytosis may change the chemical composition, followed by the building up and molding into the various shapes found. Heffernan[42] suggested that they were osmotic silica infarcts due to surface tension phenomena limiting the diffusion of the dissolved iron and other salts. Gloyne[30] suggested fibers surrounded by blood pigment. Cooke[18] believed that they were made up primarily of the asbestos spicule core upon which colloidal aggregates of blood protein and possibly soluble fractions of asbestos or iron were adsorbed and molded by currents in the bronchioles and alveoli. The fine asbestos spicules could cause minute extravasations of blood and serous exudates which first enveloped the spicules.

These curious bodies have been induced experimentally. Simson[103] states that Mavrogordato gave him for examination the lungs of a guinea pig which had been exposed to asbestos dust from the mines two hours a day for fifty days. The animal died from other cause. The microscopic examination of lung structure showed a slight generalized fibrosis and the curious bodies similar to those found in the human. Gloyne[30] *injected* asbestos dust into animals and after twelve days found foreign body giant cells but no curious bodies.

These "curious bodies" are generally conceded to be absolutely characteristic of pulmonary asbestosis. It is unfortunate that there has been a confusion of terms in connection with the foreign body findings in the lungs in this condition. The term "asbestos bodies" has been used to designate all of them, but it is often employed in connection with the "curious bodies" alone. The latter term is not a good one, but a better one may be forthcoming when the true nature of these bodies is determined. As a matter of fact, each form of body should have a specific name. Wood and Gloyne[129] believe that the term "asbestos bodies" should be restricted to the "curious bodies," and that the latter term should be dropped. It would seem to us that "asbestosis bodies" would be more appropriate, as they are characteristic of asbestosis and do not contain asbestos except as the primitive nucleus.

Methods of Isolating or Obtaining the Asbestosis Bodies. Gloyne[30] was not able to obtain them by swabbing the nose or mouth. Incidentally he failed to find any in the sputa of workers, but stated that those ex-

amined seldom yielded sputum. Haddow[36] reported finding them in sputum in one instance and also commented upon the rarity from this source. They are more likely to be found in advanced cases. Lynch and Smith[67] examined the sputum from many workers and found the bodies in some but not in others. Special preparations of the specimens are required.

Gloyne[30] first found the bodies in the juice expressed from autopsied lungs in one case. It was in the bodies taken from this case that he determined the single, slender central asbestos filament. This method of finding the bodies is now recognized as an easy means of biopsy determination.

Stewart and Haddow[112] were able to find the bodies after exploratory puncture of the lung in one case but not in a second.

Microscopic study of lung sections is, of course, the final positive means of diagnosis in all instances.

Symptomatology. The symptom-complex of pulmonary asbestosis may be of interest to roentgenologists, especially because the condition is a rather new one in the group of pneumoconioses, or, rather, an old one come to light and extensively studied. We have made a composite grouping of symptoms assembled from the reports of Wood,[128] of his 15 cases, Haddow,[36] Stewart and Haddow,[112] Soper[108] and Wood and Gloyne,[129] including 22 cases additional to those reported by Wood, as follows:

(1) *Onset.* This is variable and depends upon the exact occupation and the quantity of dust inhaled. Both are important, for the individual may not be engaged in a very dusty duty, but may be working in a room made very dusty by another procedure in the manufacturing process. Wood states that symptoms may appear comparatively early and gives as the time limits one and fourteen years. Haddow places the average period at about five years, and states that the condition is usually recognized first during or after an attack of influenza or winter cold. Cases are usually better in summer.

(2) *Cough.* This is a very variable symptom, sometimes nearly or entirely absent and seldom excessive.

(3) *Expectoration.* This is moderate when present, but is usually lacking except during bronchitic attacks.

(4) *Anorexia.* This is a rather constant late symptom. Haddow regards it as an indication to stop work. Individuals may then live for several years, but become progressively weaker, more emaciated and exhausted, until pneumonia or bronchitis brings death.

(5) *Dyspnea.* This is the most striking symptom and practically the most important one. It is progressive as in other forms of pneumoconiosis, whether the individual stops work or not. Wood and Gloyne speak of it as "a terrible tightness of the chest," which is very expressive. While dyspnea is due primarily to inelasticity of the lungs, which is always beautifully demonstrated by roentgenoscopic observations of the diaphragmatic excursion, it is also, in a measure, a result of interference with blood supply. Therefore, it is slow and insidious in its development, until, finally, the lungs are able to accomplish no more than just sufficient oxygenation of the blood to sustain life.

(6) *Cyanosis.* This is a very frequent late manifestation.

(7) *Weight Loss and Emaciation.* These manifestations are very striking in the late stages. They are out of all proportion to the physical signs, and thus differ from tuberculosis alone.

All of these symptoms are more or less those found in other forms of pneumoconiosis, and a symptomatology largely applicable to all forms is placed here for emphasis on this particular one. The last three symptoms are to be emphasized in connection with the sand pulverizing industry.

There is an interesting skin lesion found in connection with the asbestos industry known as the asbestos corn. It has been mentioned particularly by Gloyne and by Soper, among the writers on pulmonary asbestosis. The fine asbestos fibers penetrate the superficial layers of the epiderm

like thistle thorns and produce small corns or hypertrophies of the epiderm around them. No asbestosis bodies have ever been found in these lesions.

Roentgenographic Appearances. Comparatively few of the reports on pulmonary asbestosis contain roentgenographic findings, and in many of those which do, the descriptions are not so scientifically made as to permit of easy comprehension or interpretation. Most writers who describe the appearances or mention them casually seem to regard them as most unusual or characteristic of the occupation, notably Wood,[128] Wood and Gloyne[129] and Merewether.[72] It is true that they are unusual, but we would hardly regard them as characteristic for the reason that other dusts induce quite similar roentgenographic appearances. In all industrial pneumoconioses in which the roentgenographic appearances deviate from the stereotyped description first given to those of the hard rock miners one must become familiar with those of the industry and correlate them with diaphragmatic excursion, clinical findings and degree of disability represented before being able to interpret the findings for that particular industry. For example, from the roentgenograms of 17 asbestos factory employees examined by one of us in 1917 and reported by us in 1926,[91] the appearances were not regarded as of any particular moment, but simply as minor changes such as are frequently found in connection with slowly fibrosing dusts. Quite recently, on reviewing these roentgenograms with Dr. J. V. Sparks,[110] who made the roentgenological studies of Wood's cases, referring to our records of the diaphragmatic measurements, and with a knowledge of the peculiarities of the asbestos industry, particularly from the standpoint of roentgenographic appearances, we at once realized that our first interpretations were based upon an entirely erroneous conception. It is questionable whether anyone viewing a number of roentgenograms of atypical pneumoconiosis representing several industries that we know of could pick out the ones of asbestosis subjects alone. All of the cases represented in the series just mentioned were only moderately advanced. In some roentgenograms of asbestos factory workers recently seen with Dr. Lanza[65] we noted that there was a direct progression into a terminal diffuse fibrosis without any nodular predominance. This terminal stage seemed to have been reached in about twenty years on an average. Nevertheless, in some instances the nodular fibrosis was quite evident.

Wood[128] has given a very excellent description of the roentgenographic findings in the 15 cases examined, and this has been corroborated by Soper[108] in one case, by Oliver[86] and by Wood and Gloyne.[129] Our interpretation of these findings was that there had been a rather predominant early interstitial fibrosis, with, later on, an associated soft nodular fibrosis. The transition to the third stage, if we should adhere to that term, or at least to the terminal stage, would seem to have been mainly through a continuance of the interstitial predominance with very little prominence of nodular fibrosis. The early interstitial predominance was described as resembling a ground glass appearance.

On reviewing our own roentgenograms with Dr. Sparks during his recent visit to this country and comparing them with the excellent roentgenograms of some of Wood's cases, we found a great similarity in the appearances. The early evidence of the condition was a faint homogeneous haze in the lower part of the mid lung field which seemed to correspond to the appearance we have previously suggested as an early predominance of interstitial fibrosis (Fig. 9). This haze spreads through the lower half or two-thirds of the lung field and may almost obscure the domes of the diaphragm later on, with very little evidence of nodular fibrosis. With it, there is a very decided restriction in movement of the domes of the diaphragm without the appearance of pleural adhesions, which seems to be proof of the general fibrotic nature of the process. Thickened pleura does exist,

of course, as in any fairly well advanced case of pneumoconiosis. The most unusual feature of the condition seemed to us to be the fact that in both sets of roentgenograms the appearance seemed to begin more often on the *left* side than the right and progressed more on that side. This is the reverse of what is the rule in all other occupations we have studied. Merewether[72] states that it begins on the right side, as one would expect, and the cases we observed may have been examples of the exceptions which are occasionally observed in

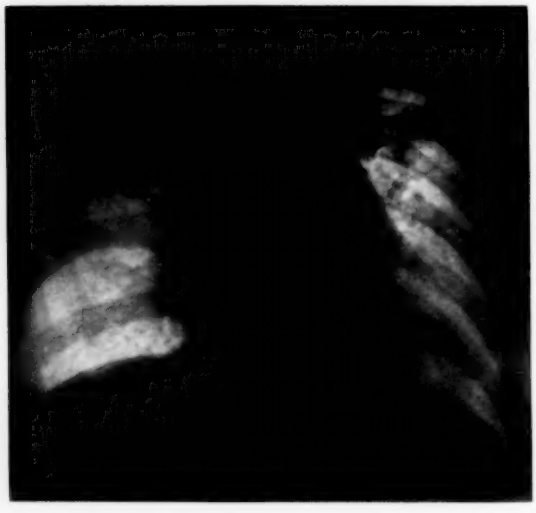


Fig. 9. Pneumoconiosis in an asbestos worker. Male, aged forty-three, employed for seventeen years and a superintendent at the time of examination. There are two predominant types of fibrosis in this case—perivascular-peribronchial-lymph node and fairly advanced interstitial. The latter is indicated by the general haze toward the bases, and more on the left side. Note the partial obliteration of the left heart border. The size of the cardiac shadow is due to the old technique of many years ago. Diaphragm excursion ½ inch each side, ordinary respiration, and 1¾ inch on forced respiration.

any industrial pneumoconiosis. We noted the same tendency to obliteration of the left cardiac border as mentioned by Wood, because of the diffuse fibrosis and the prominent trunk shadows. Wood states that the late stage may or may not show consolidations. Wood and Gloyne[129] state that the ground glass appearance in late cases on careful analysis resolves itself into a fine mottling and linear shadows which, toward the base, may look like cobwebs.

It is evident that the nature of these changes in the lungs requires the best type of roentgenograms for their portrayal. Also, the seriousness of what may seem to be minor changes to the uninitiated requires a roentgenoscopic study of diaphragmatic movements to make one realize the actual state of disability present. It is evident also, as Merewether states,[72] that an opinion as to the degree and intensity of an asbestosis fibrosis based upon a comparison of roentgenographic changes with those shown in standard silicosis films will be an underestimate.

Of the 363 cases examined by Merewether and Price, 133 had roentgenographic studies. Of these, 52 were said to have presented appearances of diffuse fibrosis and 22 were suspicious.

We have had the opportunity recently of examining in consultation the roentgenograms of 58 men employed at the mines in many occupations and during periods varying from eight months to forty years. Of this number, 15 showed definite evidence of pneumoconiosis, one was doubtful and 42 showed no lung changes. The longest worker showed a moderate nodular stage of the condition. The shortest times in which definite changes were indicated were four years for one first stage case, five years for another and five years for one early second or nodular stage case. The worst case showed a diffuse third stage fibrosis after thirty-one years' occupation.

Asbestos mine dust is not comparable to that of the factories for many reasons. Some silica is present, but there is not the great concentration of asbestos dust in the mine as compared to the factory. From our own experience so far, we would not regard the hazard at the mine as very great.

Prognosis. It seems to be the rather general opinion that the prognosis in pulmonary asbestosis among factory workers is to be regarded as grave without adequate protection, in a large number of cases

among those who work where there is great concentration of dust. The condition is apparently progressive even after cessation of occupation. Merewether and Price state that with continued exposure to high concentration dust fibrosis may be fully developed in from seven to nine years and death may result in about thirteen years. With less concentration, fibrosis may not be fully developed for fifteen, twenty or twenty-five years. Inhalation of dust in high concentration results in a more marked degree of fibrosis in a shorter time than when the concentration is lower.

Predisposition to Tuberculosis. The condition of pulmonary asbestosis being a new child in the pneumoconiosis family, a great amount of interest centers around the incidence of tuberculosis. Among the early case reports referred to in the beginning of this occupational section, pulmonary tuberculosis was reported as an accompanying condition in a few instances. Cooke's case had advanced tuberculosis. Simson reported one case which died with tuberculosis and one without evidences of the infection, He thought that we could not as yet formulate any definite opinion as to the frequency or the predisposition. Simson quoted Hoffman[48] as reporting 13 deaths among asbestos workers, 3 of whom had tuberculosis. He also quoted Collis[12] as reporting 5 deaths from tuberculosis among less than 40 workers at a factory. Wood and Gloyne[129] referred to 3 cases showing evidences of tuberculosis at autopsy. Haddow[36] observed many asbestosis cases and among them 4 died. He did not believe that the condition predisposed to the infection, at least not as a rule. Merewether and Price stated that asbestosis differs from silicosis in the distribution of the fibrous tissue, in more rapid development, in roentgenographic features and possibly in a *lessened susceptibility to tuberculosis.* Merewether[72] states that out of 374 cases examined, evidence of active tuberculosis was found in three. He thinks that while there is no outstanding susceptibility proved, he does not agree that the question has been finally settled as yet.

Compensation Laws. Legislation in many countries and states provides for compensation for silicosis, which is a condition produced by silica. Asbestos is a silicate, and if we are to regard asbestosis as a silicosis, as has been suggested but not proved, the latter condition is only indirectly caused by the asbestos. Certainly the legal status of asbestosis as silicosis has not been established. In some instances asbestosis has had to be made a compensable disease.

Hard Rock Mining. This group of workers comprises the largest engaged in any single hazardous industry throughout the world, provided the rock is of a siliceous nature. The large amount of dust evolved in the various processes of mining is always dangerous unless adequate protective measures are adopted. The drillers and those working with them or near them are prone to be the most exposed. If the fine dust is allowed to escape, it remains suspended in the air for hours. Blasting always stirs it up. Without protection, the usual typical symptom-complex and the roentgenographic appearances develop early and progress rapidly, and the workers are predisposed to tuberculosis. More has been written upon the hazards of this industry than those of any other. Numerous writers have been extensively quoted elsewhere. Many more or less similar industries and their hazards have been described in detail, such as the drilling in coal mines, granite cutting and sandstone quarrying.

The most detailed descriptions of hard rock mining have emanated from South Africa through individuals associated in medical work or other ways with the Rand gold mines. These mines are so often referred to in the literature that a short abstract of the description of the region and of the character of the rock may be of interest. Cluver[10] states that the first gold mining in South Africa started in the Transvaal in the 70's, and the first gold was taken from the Witwatersrand in 1885.

This field is on a plateau of 6,000 feet elevation. The "rand" or ridge is 60 miles long and divides the water shed in two. The gold beds are composed of quartz pebbles bound together by a siliceous matrix in which the gold is distributed. They run in veins between quartzite. The quartzite layer, containing 95 per cent of silica, must be mined through in order to reach the blanket (86 per cent silica) in which the gold lies. The gold containing rock must be crushed.

Literature dealing with the mining industry in Australia is also quite profuse, and was quoted extensively in our previous communication. Metal mining in America is a great industry, but little literature is to be found in connection with it. Extensive investigations with more or less roentgenological studies have been made and the results reported through the agencies of the U. S. Public Health Service and the U. S. Bureau of Mines by Lanza and Childs,[66] in 1917, in connection with the zinc miners in Missouri; by Harrington and Lanza,[38] in 1921, with the miners around Butte, Montana and by Higgins, Lanza, Laney and Rice,[46] in 1917, with the miners in the Joplin district, Missouri. The United States Bureau of Mines[98a] publishes annually an abstract of literature on the subject of silicosis and other mine hazards.

We have had the opportunity of examining the roentgenograms of several hundred miners working in various metalliferous ores for the U. S. Bureau of Mines and others.

Because of the similarity of the work, evolved dust and the resulting hazards in connection with rock drilling and other occupations in the subway and tunnel construction in New York City to those of hard rock mining, a clinical and roentgenographic study of some of the employees and an investigation of the physical problems in these operations as possible dust hazards was undertaken by the New York Tuberculosis and Health Association, the DeLamar Institute of Public Health of the College of Physicians and Surgeons of Columbia University and the Metropolitan Life Insurance Company in collaboration.[102] Included in the complete report was a study of the rock drillers, blasters and excavators by Smith[104] and an investigation of the dust problem by Fehnel.[24] A brief abstract of these studies is instructive. As one of us had the privilege of examining the roentgenograms of these workers, the opportunity was most important for the reason that it was the first occasion upon which we were confronted with the shortcomings of our American stages of pneumoconiosis. The rock in which these men worked was stated by Smith to be mostly schist, gneiss and limestone, and mainly the first which is rich in quartz. Fehnel found on various estimations that the total silica in combination varied from 56 to 94 per cent and the free silica content varied from less than 1 to 84 per cent. He regarded the degree of harmfulness of the dust arising from drilling operations as comparable to that of the Butte mines.

The diagnosis of the condition of silicosis was based mainly upon roentgenographic appearance. The study included 208 rock drillers, blasters and excavators. One of us had the privilege of examining the roentgenograms through the courtesy of Dr. Smith. Silicosis was diagnosed in various stages of progression in 118, or 57 per cent. Of these, 23 per cent of the men examined showed the haze which Dr. Smith and we at the time decided to designate as the ante primary stage. It is now realized that many of these may have represented what we have recently decided to designate as an early interstitial predominance of fibrosis. Nineteen per cent of the chests examined showed what we were accustomed to call first stage appearances; 7 per cent, more or less nodulation, and 8 per cent the third stage of diffuse fibrosis. Eighteen of the 32 men in the advanced group had worked only in New York City. Distressing dyspnea was noted in only 3 or 4 instances. Only 2 or 3 complained of anorexia, loss

of weight and loss of strength. Only one man in the second and third stage groups had been exposed less than ten years and seventy-five per cent of them had been exposed twenty years and over. Most of these men were engaged in tunnel and other underground work and these groups included more drillers and blasters than the other groups. The exact incidence and progress of tuberculosis among these workers does not seem to us to be definitely proved by the report.

The men reported as showing what we have recently designated as the early interstitial predominance of fibrosis would not seem to be examples proving a rapid progress of this type for the reason that a large proportion of them were said to have been engaged in open excavating and they showed no demonstrable dyspnea and no disability, and this group as a whole was regarded as rather unimportant. In our opinion, this goes to show that the exact significance of this type of fibrosis must be interpreted in correlation with the hazard of the occupation, time at work, volume of dust, serial studies, and, above all, in connection with limitation of expansion and diaphragmatic excursion. The same appearance if noted in sand pulverizers and asbestos workers may mean much more.

The Silicosis Committee organized for the study of the New York City drillers and excavators made the following recommendations in the report:

"1. Rock drilling blasting and excavating in New York City constitute a serious hazard to the health of the workers, owing to the constant exposure to silica dust, resulting in silicosis and tuberculosis. Remedial measures are urgently needed.

"2. Efforts must be made immediately to improve markedly, by controlling the dust concentration, the conditions under which the men employed in these occupations are compelled to work.

"3. Compensation should be granted by law for disability due to silicosis."

The Abrasive Industry. The use of various abrasives in the grinding and polishing of metals and tools is capable of producing early and rapidly progressing pneumoconiosis, but the danger depends to a large extent upon the character of the abrasive material or device used. Sandstone, usually employed as a wheel, is the chief offender, and is deserving of the most discussion. Silica in a more or less finely divided state is constantly thrown off.

Fig. 10. Pneumoconiosis, with terminal diffuse fibrosis and extensive areas of massive fibrosis. Male, aged fifty-eight, worked as a tool grinder for seven or eight years and afterwards as a farm laborer. The chief complaints were abdominal, with, in addition, dyspnea, loss of weight, cough and mucopurulent expectoration. Tuberculosis uncertain. Clinical chest findings essentially those of pneumoconiosis. This case was previously reported as one of left phrenic nerve paralysis, but we concluded later that the elevation and phenomena of the left dome of the diaphragm were due directly to the fibrosis. (See unusual complications.)

Metal dust in minute particles is also probably suspended in the atmosphere to a certain extent, but plays little or no part in the damage to the lungs. Russell, Britten, Thompson and Bloomfield[98] found 23.3 to 30 million particles per cubic foot of air in the dust to which tool grinders

were exposed in their investigations of the Barre granite industry, compared to a possible maximum safe limit of 10 million. Some of this dust was probably granite. Two sandstone grindstone workers we examined showed advanced terminal diffuse fibrosis after five and eight years' occupation (Fig. 10).

The wetting of sandstone grindstones is of doubtful value, as is illustrated by a case which we have previously reported. This man was exposed for twenty years to the dust in a room in which were operated 24 *wet* sandstone grindstones for sharpening knives. He never operated one himself and worked 25 to 50 feet from the nearest one. He began to cough and lose weight four years before our examination, which showed an advanced diffuse fibrosis of the conglomerate nodular type. Winslow and Greenburg[127] state that investigations have shown that the protection afforded by wet grinding as compared with dry and the use of an exhaust is illusory in most instances. In this connection, attention is again called to Hoffman's quotation[49] of the report of the British Home Office to the effect that of 495 wet sandstone hand grinders with an average occupation period of 21.49 years, 73.97 per cent showed evidences of lung fibrosis. Among the wet sandstone machine grinders 37.5 per cent showed fibrosis, while among the dry grinders the proportion was but little higher, being 38.8 per cent.

Middleton[75] states that racing and trueing up of grindstones has been a very dangerous occupation in the past, but dust removing devices have made it much safer in more recent years. The dangers of sandstone working are to be found also in the quarrying of the stone, and the later dressing. These occupations will be discussed later because of some interesting features in connection with them.

The harder abrasive materials such as carborundum do not appear to be really dangerous, first, because the tools do not wear away so fast as sandstone, and, secondly, because the amount of uncombined silica is small. Middleton calls attention to the lessened hazard from silicosis and tuberculosis in abrasive industries because sandstone devices are being replaced by carborundum, which is much safer. While carborundum may not be entirely silica free, there is every reason to believe that it is much safer than sandstone. One man examined by us who had been a metal grinder with carborundum and emery abrasives for twelve years showed very little evidence of pneumoconiosis.

We have previously discussed the manufacture of carborundum, a silicon carbide, in sufficient detail in the light of our present knowledge.[90,91]

Clark[9] has reported the roentgenographic findings in a group of workers with an abrasive composed of aluminum oxide and silicon carbide. In 1924, he examined 79 of the men who had been exposed to the dust for 10 years. Up to 1928, 6 had died, and out of 69 of the original 79, 12 showed no evidences of silicosis; 43 showed first stage changes and 3 exhibited those of the second stage or true silicosis. Of these 3, only one had been exposed to the abrasive dust alone, and that was for a period of twenty-six years. Reports were made also on newer groups. In this particular plant, examinations were made annually of the workers, which reflects great credit upon the company.

Willis[125] exposed guinea pigs for three years to a dust composed of 98 per cent silicon carbide and 0.5 per cent silica, which is an artificial abrasive. They were exposed in a very dusty atmosphere on an average of fifty hours per month, with occasional weeks of rest. At the end of one year, dust cells were found in the alveoli and just beyond the alveolar walls. Occasionally they were seen within the alveolar walls. Beyond these points they were seen in the walls of the bronchi, in lymphoid deposits and under the pleura in small patches. Dust itself was present in masses of lymphoid tissue which showed some hyperplasia of cells. There was some thickening of the walls of the bronchi and

vessels. After three years, these latter changes were found to be only a little more marked. There was surprisingly little fibrosis, most of the peribronchial and perivascular thickening being due to cellular infiltration. The animals did not seem to be unduly predisposed to tuberculosis.

The Sandstone Industry. The remarks in connection with the hazards of sandstone abrasives would indicate that any work in the quarrying, drilling or dressing of sandstone would also be hazardous because of the high silica content of the dust evolved. Rapidly progressing silicosis and a predisposition to tuberculosis would be expected. As a matter of fact, one of the most interesting examples of the exposure of individuals to silica in the progress of civilization is to be found in the underground work in and around Sydney, New South Wales. Here, a greater part of the excavations, tunnelling and trenching for all purposes in the building and betterment of the city have had to be carried out in solid sandstone. Badham, Rayner and Broose[2] state that this stone contains by chemical analysis 86 to 95 per cent of insoluble silica. Much of the work of the past has been done "under grossly unsanitary conditions, and these works remain in service to-day—unrecognized monuments to the men who gave their lives in the making of them." Needless to say, attempts have been made to better these conditions.

In contrast to this are somewhat better reports from the chief center of the sandstone industry in America, located in northern Ohio. In 1927, Kindel and Hayhurst[69] reported stereoscopic roentgenographic examinations of 919 men who had worked in the sandstone quarries of Amherst, Ohio. The composition of the stone was 94 to 97 per cent silica. A positive diagnosis of silicosis was made in 260, or 28.5 per cent. Thirteen men, or 1.4 per cent, showed silicosis with tuberculosis, and 5 more, or 0.5 per cent, tuberculosis without silicosis, which was not considered above the normal incidence. The great majority of the men affected showed silicosis after ten years and rarely any evidence of the condition in one to three years. The average exposure was 16.24 years for beginning evidences of silicosis. The condition was regarded as slow in inception and incidence. The explanation offered in a later article by Hayhurst, Kindel, Neiswander and Barrett[41] was the possible influence of the matrix holding the silica crystals together in slowing the incidence and progress of the silicosis. This matrix was said to consist of carbonates, silicates, kaolin forming substances and sulphides and oxides of iron. One might compare this supposition with the theory of Heffernan and Heffernan and Green. Such an explanation has not yet been generally accepted because of the lack of absolute proof.

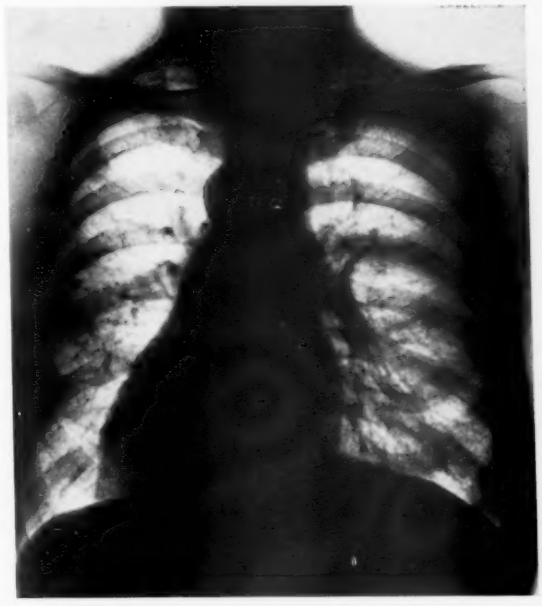


Fig. 11. Pneumoconiosis of only peribronchial and perivascular predominance after twelve years' occupation as an abrasive worker in grinding steel with emery and carborundum. Male, aged forty-four. Note the greatly intensified trunk shadows, without mottling or haze. The appearance would also indicate that metal dust, per se, plays little or no part in casting the shadows. This patient had no chest symptoms.

Sand Pulverizing. Recently we have had the opportunity of making roentgeno-

logical studies of the chests of a group of workers in some sand pulverizing plants. The first study included 14 individuals from one plant, all but one of whom were negroes. All of them except two foremen were engaged in bagging the pulverized sand. The dust was delivered to the bags in chutes and was said to be quite hot, and many of the men stated that it would burn the skin of their hands so that they could work only intermittently in order to give the skin a chance to recover. We were rather led to believe at first that the heat of this dust played some part in the damage to the lungs, but we later entirely dismissed this idea as it seemed inconceivable that fine dust in the atmosphere could have such an effect.

In this particular plant, the sand was pulverized through the agency of quartz pebbles in a rotating device after heating and drying. The broken sand particles were then conveyed to trays for further heating and drying. They were then separated into three sizes mainly, and then entered the chutes for bagging. Working with the finest dust was said to be productive of the most serious effects upon the workers. The bagging is now said to be the only really hazardous occupation. Naturally the finely pulverized dust is heavy and closely packed as it lodges in the bags, and it was stated that a few of these burst every day and the contents were scattered on the floor at the feet of the worker. He was constantly stepping around in a deep layer of dust and stirring it up in the air, and thus adding to what was already suspended in the surcharged atmosphere. The dust cloud in the air of the plant was described to us by some of the men as resembling a dense fog, but these statements have been denied by Dr. H. F. Smyth, who made dust counts in one of the plants and saw no such dust clouds. His counts approximated 8 million particles per cubic foot of air. This is below the figure of 10 million regarded by Russell et al[98] as a permissible maximum among granite cutters as not likely to produce rapidly progressing silicosis nor to predispose to tuberculosis. It should be borne in mind, however, that granite dust contains but 35 per cent of free silica, whereas ground sand would contain a much higher percentage. So 8 million particles of high free silica content means much more than 10 million of granite dust. It was said that silicosis had developed in several women in this plant who were engaged in sewing up holes in bags which had been used and in which a considerable amount of dust was retained. One of these has just been examined by us and her lungs showed some evidences of silicosis.

The various sizes of pulverized sand particles are used mainly in the manufacture of soap powders, sand soaps and glass. Powdered sand is also employed in the manufacture of vitreous paint. This distribution of the products brings up the transfer of the problem of a hazard to other industries.

The longest period of occupation of any of these individuals was two and one-half years at intervals, and the shortest was said to have been thirty-five days during a period of a little over one year (Fig. 14).

According to the information we were able to obtain, the symptoms were dyspnea, cough, hemoptysis, night sweats, asthenia and extreme weakness. The men were not able to work continuously, but would have to discontinue for two or three months at a time. All 14 cases presumably showed evidences of silicosis, but in 3 of them there was so much extensive tuberculosis that the other condition was difficult to differentiate. The other 10 cases exhibited lung changes quite different from the usual appearances of pneumoconiosis.

The earliest appearance noted was a characteristic slight haze in the right lower lobe, such as we have suggested as a possible fourth stage, but have later thought advisable to designate as a predominant early interstitial fibrosis. A little later a slight fine nodulation might be observed but was not the predominant feature (Fig. 12). This, by the way, seems to be the appearance characterizing the fibrosis of

early asbestosis, although at a longer period of time. The next change was a general haze throughout the lower two-thirds or more of the right lung, and with the beginning of the appearance at this time on the left side (Fig. 13). Sometimes a thickening of the pleura was suggested as a part of the makeup of this haze. Interlobar pleural thickening was sometimes encountered, best shown in the lateral view. Still further progress of the condition was indicated by a diffuse fibrosis of the interstitial type with some conglomerate mottling in addition, but never as a predominant feature (Figs. 14 and 15). Even this appearance became far advanced on the right side before there was much progression evidenced on the left. At about this time, nodulation would become definitely apparent on the left side, but here, again, it was not predominant. In some few instances there was

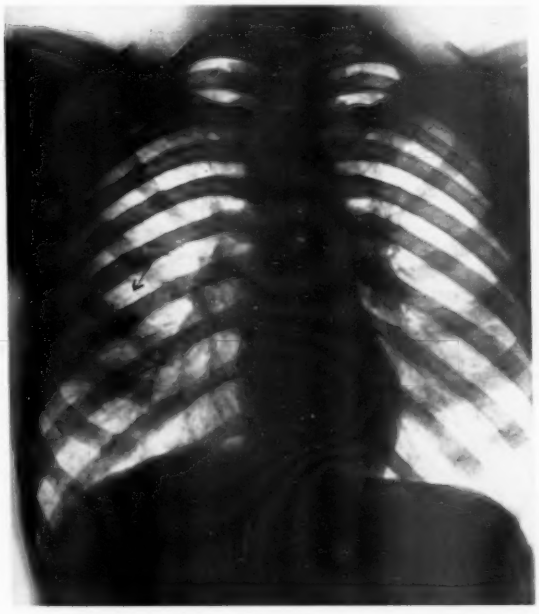


Fig. 12. Pneumoconiosis, with early interstitial predominance of fibrosis. Male, negro, aged twenty-nine. Worked in sand pulverizing plant for several months. Has a non-productive cough. The only really significant finding is a general haze in the center of the lower half of the right lung field, which we have interpreted as evidence of an early interstitial predominance of fibrosis in this region. Diaphragmatic excursion 25 mm. right and 33 mm. left side.

Fig. 13. Pneumoconiosis, with early interstitial predominance of fibrosis, more advanced than in Figure 12. Male, negro, aged thirty-six. Worked in sand pulverizing plant. There is a general haze in the right lower lobe with extremely fine mottling seen in the roentgenogram but not reproducible in a reduction. The same change is beginning in the left lower lobe. Diaphragmatic excursion—right dome 13 mm. and left dome 30 mm. The predominance of interstitial fibrosis and greatly restricted expansion in a short-time worker in a hazardous dust gives a bad prognosis. Nodular fibrosis will never predominate in this case.

a decided tendency toward conglomerate nodulation, although it was not the predominant feature. Three cases showed what may have been either massive fibrotic areas or tuberculous consolidations. Even the man supposed to have worked only thirty-five days showed the diffuse haze in the right lower chest with a tuberculous lesion in the right upper. This man died of tuberculosis soon after our examination, and he will be referred to later (Fig. 14). He may have had tuberculosis first, as was suggested in another case (Fig. 6). In all of the cases there was more or less diaphragmatic restriction, especially on the right side.

The characteristic features in these

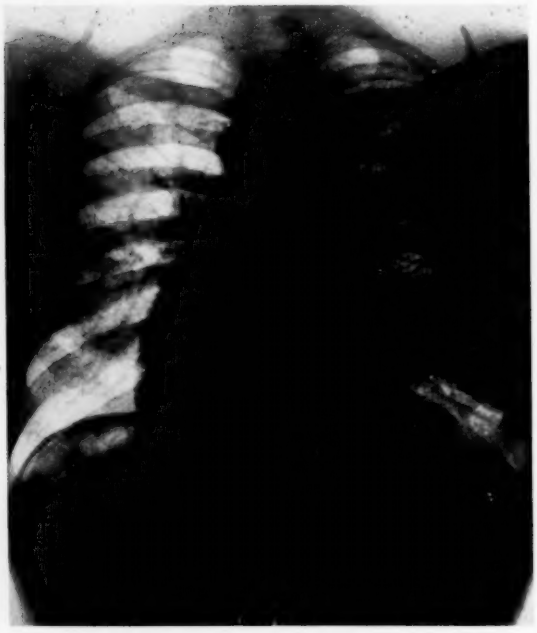


Fig. 14. Pneumoconiosis, with advanced early interstitial predominance of fibrosis. Male, negro, aged twenty-eight. Worked as a bagger in a sand pulverizing plant only thirty-five days during a period of less than two years. Was a railroad laborer before. There is an advanced early interstitial fibrosis in the right lung beginning to approach a terminal diffuse fibrosis of the interstitial type, although the left lung shows only the early stage. The dense area in the right upper lobe is probably a tuberculous focus. This man died of tuberculosis a few weeks later. (See Case 1, in table of silica in lungs of autopsied sand pulverizers.) There is no way of telling whether this man developed tuberculosis before or after he was exposed to the dust.

workers were the early predominant interstitial fibrosis in men of short periods of occupation, with an early restriction of the dome of the diaphragm on the affected right side, and later on the left just as soon as there was the first evidence of the characteristic faint haze. These features at once suggested a bad prognosis. Here we have an occupation in which roentgenographic evidence alone would be of little value, especially in the relatively early stages. Roentgenoscopic observations, symptomatology and a knowledge of the industry were absolutely essential in the correct interpretation of roentgenograms. Too often are conclusions based upon purely roentgenographic evidence, and even on very mediocre roentgenograms, in the haphazard investigations of industries.

It is very evident that the usual numerical stages of progress which have been rather generally employed in the roentgenographic aspect of pneumoconiosis, especially in this country, could not be applied to this industry. It was these cases, the appearances in the asbestos workers examined by us many years ago and the reports of various writers on asbestosis, the roentgenographic findings among the granite cutters and in the workers in several other industries that indicated to us the fallacy of adhering to definite numerical stages of progress applicable to general pneumoconiosis and necessitated the adoption of a pathologic-roentgenographic classification such as we have already suggested. It is by no means a final one and is a suggestion for our own use as well as to others.

Fig. 15. Pneumoconiosis, terminal diffuse fibrosis, interstitial type. Male, negro, aged forty-six. Worked as bagger in sand pulverizing plant eighteen months but stopped two years before this examnation because of cough, extreme dyspnea and loss of weight. Tuberculosis cannot be proved or excluded. Worked on farm before. Diaphragm excursion 35 mm. right and 24 mm. left side.

It was assumed that 3 of the 14 cases in this group showed evidences of tuberculosis because they showed changes in the upper lobes out of proportion to appearances in the lower portions of the lungs, in addition to some of them showing cavities. A later case of a foreman not included in the group showed a mottling in the right upper lobe without evidence of silicosis below. The appearance was not typical of tuberculosis, but we had no other way of interpreting it except as a bronchopneumonic tuberculosis with little or no allergic reaction.

Several workers in the plant died. We are indebted to Prof. Louis Gershenfeld for information in regard to the estimations of silica contents in the lungs of 4 cases autopsied as well as for descriptions of the plant and its operation.

	Per Cent Ash in Dry Lung	Per Cent Silica in Ash	Per Cent Silica in Dry Lung
Normal female	4.03	7.75	0.31
Normal male	5.10	13.0	0.66
Case 1*	6.17	29.3	1.81
Case 2	8.01	40.6	3.29
Case 3	6.94	30.3	2.10
Case 4	6.59	37.2	2.45

* This is the same case as represented in Figure 14. He died a few weeks after our examination.

It will be noted in the above table that the silica content of the ash was 30 to 40 per cent, whereas that in normal individuals was 7.75 to 13 per cent. These individuals were getting an overwhelming dose in a short time. Much of the silica coming into the lung could not have become active in the production of silicosis at once, but even had these individuals stopped work some time before they died, the eventual outcome would have been the same as though they had continued, although possibly in a slightly longer period of time.

The foregoing table of percentages of silica in the ash of the lung may be compared to those found by Riddell and Rothwell[95] in 3 autopsied miners in Ontario, which were as follows:

Case 1. Ante primary stage of silicosis, died of other cause. The interstitial tissue of the alveolar walls was increased and there was much general fibrosis following the lymphatics. Silica content in ash of lung 18.86 per cent.

Case 2. Primary stage of silicosis, died of pulmonary tuberculosis. Silica content in ash of lung 15.23 per cent.

Case 3. Secondary stage of silicosis with nassive consolidations, died of silicosis, no tuberculosis. Silica content in ash of lung 33.26 per cent.

We know that 2 of the cases we examined died later of tuberculosis. The cause of death in most of the workers who died was said to have been pneumonia. Almost all of these workers were negroes from the south who must be regarded as more susceptible to tuberculosis if exposed to excessive silica inhalation.

Just at the completion of this presentation we have finished the examinations of 9 additional sand pulverizers, some of whom worked in the same plant, and possibly all of them. We have not completed the study of all of the roentgenograms at the time of this writing. Two cases had definite tuberculous lesions, and in one, the infection evidently began or became active after starting in the work. One of the men had worked for eight years in the plant, mostly as a foreman, and showed mainly a very definite and increasing peribronchial-perivascular-lymph node predominance which did not seem to conform to the findings in the other workers. There was also some interstitial fibrosis and a faintly visible nodulation with very small, soft spots. This individual was the only white man in this group.

We have entered into many details in connection with this industry because it is a comparatively new one for study and in the literature.

Middleton[75] has referred recently to some cases of acute silicosis among workers with ground silica powders used with soap, and

mentions the fact that such powder is also used in vitreous enamels, filling material in wood working and in the manufacture of insulating material. The use of vitreous enamel paints will be discussed later.

Heffernan[42] states that the most rapidly developing cases of silicosis reported in the literature have been the packers of siliceous scouring powders, consisting mainly of strong alkaline dried soap and finely ground silica. He believes that after the phagocytosis of the dust, the alkali favors the rapid formation of fresh silica hydrosol (see pathology). Death occurs very quickly among these workers. According to his theory, water is all that is required for the almost immediate production of active silica hydrosol. The colloidal activity of the silica begins almost immediately after the dust reaches the lungs, instead of waiting for the slow natural hydration of the silica particles by the faintly alkaline tissue juices. He has suggested that the efficiency of these silica soaps is due largely to the adsorptive powers of freshly made silica hydrosol in addition to any abrasive action. This adsorptive property originates soon after the powders are wet.

Sandblasting. The use of the sand blast is a procedure carried out in a large number of industries. It is productive of a large amount of fine and nearly pure silica dust, especially as the force of the blast and the impact fractures the particles of sand and they become finer and finer unless the smallest ones are drawn off by exhaust. There are no collective data on the process as a whole. von Müller[82] examined 26 men engaged in sandblasting and found pronounced roentgenographic evidence of silicosis in 16, and 2 of this number had pulmonary tuberculosis. The infection was found in 2 others without silicosis. The exposure time was comparatively short, being under three years, but was eight years in one of the affected men. Four of the 26 workers soon died, and 4 were examined six to nine months later and showed considerable progression. Preventive measures seemed of little avail, whatever they may have been. Aside from dyspnea and greatly diminished expansion, the signs and symptoms were surprisingly slight.

Most of the studies on sandblasting have been made in connection with individual industries in which the process has been used as only a part of the manufacturing procedure. Most of us are familiar with the sandblasting of buildings to clean stone or marble facing, for the purpose of smoothing or polishing metal surfaces and the etching of granite tombstones or building stone.

Hamilton[37] calls attention to the great hazard of sandblasting in the preparation of sanitary ware before the enamel is applied. A foreman in one factory informed him that a worker was never known to last more than four years. In sanitary ware manufacture, sand is used also in the molding, and contains 50 to 70 per cent of silica. The product is then taken to the finishing department where the sand blast is used. This sand is rich in silica, and there are always clouds of dust suspended in the air. Satisfactory protection is difficult. In many plants helmets are used, with or without respirators. This author states that the workers are carefully watched for the appearance of evidences of silicosis. There are, of course, British regulations governing this industry. In this connection, Middleton[75] states that the sandblasting of metals and glass is not entirely safe even with protection.

The sandblasting of buildings, even though out in the open, does not seem to be entirely free from risk. We have noticed that where this is being done, the finer particles are carried over more than a city block to such an extent as to make a perceptible covering of fine sand over the street.

Some sandblasting can be carried out with fairly good protection as, for example, in the granite industry. One is amazed in watching the granite cutters using the pneumatic tool with their noses buried in a cloud of dust, whereas the sandblasting is usually done under cover, with the oper-

ator looking through a window and his arms through openings in the shield. In the Barre granite works the dust count for sand blasters as determined by Russell, Britten, Thompson and Bloomfield[98] and also quoted by Hatch, Drinker and Choate[39] was 6.2 million particles per cubic foot of air, whereas 10 million was assumed to be a fairly safe maximum.

Excessive quantities of fine sand in the atmosphere may cause more or less silicosis under many unexpected conditions. We have examined the chests of several farmers who have worked in sandy soils for a long period of years and have found what we thought to be mild fibrotic changes in the lungs unaccounted for by anything else than pneumoconiosis. The rock in the Rand mines becomes surface rock in the Transvaal and in time has become more or less pulverized. Watkins-Pitchford[121] states that he found 7 cases of silicosis out of 34,000 farmers and post and transport riders exposed to dust storms in the Transvaal. A very interesting and unusual instance has been reported by Orr[89] of a second stage silicosis in an actor who had never engaged in any known dusty occupation. It was finally learned, however, that this man had been a "buck and wing" dancer for twenty-five years, and was in the habit of scattering sand on the stage before every performance. This is an example of the often obscure occupation that can be determined only after careful investigation in some cases of evident silicosis without a history of apparent cause.

Brick Workers. Ordinary building brick materials contain clay with a certain amount of sand or free silica as a necessary constituent. It is not likely that this industry presents any dust hazards. The ordinary fire brick material contains more silica. Ganister and silica brick employed as steel furnace linings contain a much higher percentage. These are made by finely grinding quartz, molding the product with clay into bricks and burning at a very high temperature of 1,450° C.[98] They contain 90 to 97 per cent of silica. Silicosis and high mortalities from tuberculosis have been reported among such workers.

It is claimed by some authors that in the mixture of clay and silica, the former exerts some preventive influence against the production of silicosis and a predisposition to tuberculosis. Heffernan[43] in 1926 reported on a group of workers in silica brick in the Derbyshire district who used a mixture containing 84 to 88 per cent of silica obtained by crushing ganister rock and mixing it with clay. These men showed no marked manifestations of silicosis and no undue mortality from tuberculosis. It was assumed that the clay exerted some preventive influence. Smith and Collis[106] made similar observations among the Yorkshire brick workers. Heffernan[42] and Heffernan and Green[44] at a later time explained this assumed protective action as we have previously stated under the section on pathology of silicosis. Accurate dust counts are, of course, imperative before any conclusions as to protection can be drawn.

The Granite Industry. All of the various forms of quarried and subsequently dressed rock for building, paving, ornamental work and other purposes cannot be considered in the same class from the standpoint of the industrial hazards. The latter vary greatly with different kinds of rocks, because of their constituency, or with certain features peculiar to the work entailed. Some rocks, as limestone and marble, contain very little silica and not enough to do harm. Others, as the sand stone of northern Ohio, may have certain characteristics which afford protection to some extent, although this has been questioned. The granite industry has been subjected to very careful investigation in this country, especially by the United States Public Health Service, and the report of this study is one of the outstanding monographs on pneumoconiosis.[98] The workers with granite are exposed to hazards comparable to those of rock drillers in many mining industries.

We are indebted to Jarvis,[53,54,55,56,57]

Hoffman[50] and Gardner[26] for early studies in connection with this industry; to the reports of Russell, Britten, Thompson and Bloomfield,[98] of Bloomfield,[5] Thompson and Britten,[116] Gardner[27] and Hatch, Drinker and Choate[39] for the last word on the subject, and to these authors we are indebted for our modern conception of the industry.

Granite consists essentially of feldspar, mica and quartz. The first two constituents are silicates and of no particular significance. The last one gives to the rock its dangerous features. Chemical analysis of the Barre granite shows approximately 70 per cent of silica free and combined. Petrographic analyses reported by Russell et al[98] gave an average free silica content of approximately 35.2 per cent.

The process of preparation of the granite is a complex one from the standpoint of the elimination of varying amounts of dust. The rough quarry blocks are cut to dimensions, the sides are brought to plane surfaces and are then cut with letters, designs or moldings (Hatch, Drinker and Choate[39]). These processes require several kinds of tools or devices. The old hand tool, now out of date, has given place to the pneumatic tool for finishing purposes, such as lettering and carving, and its use is apparently the most hazardous occupation in the industry because of the large amount of fine dust evolved and the close proximity of the nose and mouth of the operator to the source of dust. In the surfacing machine, used to bring the rough faces to plane surfaces, pneumatic hammers are used also, but they operate on a horizontal arm and the operator is much farther away from the source of dust although it is distributed around in the general atmosphere. Saws operating with steel shot require water for cooling and the dust is not so great in amount. High speed carborundum wheels for the rough part of detail work also require water. A sand blast is operated under cover usually. The polishing mill, with heavy steel disk, and using grit, carborundum or steel shot, also uses water.

The approximate liberation of dust, mostly of a potentially dangerous size, has been estimated by Russell et al in the various occupations as follows:

	Figures per cubic foot
Hand pneumatic tools	60 million particles
Surfacing machines	44 million particles
Carving and lettering	37 million particles
Tool grinding (sandstone)	27 million particles
Lathe operating	18 million particles
General plant atmosphere	20 million particles
Polishing	9 million particles
Sandblasting	2 to 6 million particles
Sawing	4.6 million particles
Office	1.9 million particles

As has been previously stated elsewhere, it was thought possible that a dust count of 10 million per cubic foot might be regarded as a safe maximum at which the workers would probably not develop an incapacitating silicosis or be predisposed to tuberculosis. According to Hatch et al[39] attempts were made to standardize hoods and exhaust air flow to bring the excessive dust elimination down to this limit. Bloomfield[15] states that it was possible to do this in most instances in the sheds if the devices were properly applied and maintained. Thus, removal of the dangerous quantity of the dust at its source serves to protect the other workers provided the dust is properly taken away.

Roentgenographic Studies. It was found that a definite relationship existed between the magnitude of dust exposure and the development of silicosis among the workers. The incidence among pneumatic hand tool cutters as found by Russell et al was as follows:

> Earliest case seen showed early silicosis after 2 years of service. All cases seen showed early silicosis after $3\frac{1}{2}$ to 4 years of service. Earliest cases seen to show advanced silicosis after 5 years' service. Ninety per cent of cases after 8 years' service showed advanced silicosis.

The hand pneumatic tool began to displace the old hand tool about thirty years ago, and it seems probable that silicosis and tuberculosis have been much worse since the advent of the former. Willis[126] quotes

Hoffman[51] as stating that the death rate from tuberculosis among the granite cutters of the New England States was 432 per 100,000 from 1895 to 1899 and 1,056.7 from 1915 to 1918. This increase would seem to be largely a result of the incidence of the hand pneumatic tool.

The most painstaking and valuable studies have been made of Barre granite cutters by Russell and his associates.[98] They state that the roentgenological diagnosis is easy when the condition is fully established, but that the physical examination is of more importance when the disease is in its incipiency. Nevertheless, it seems as though a very early roentgen diagnosis should be possible when the characteristics of granite silicosis are known and the significance of early changes are understood as they apply to this industry, just as they have been found to be in asbestosis and silicosis among sand pulverizers. These authors state that the division into the old numerical stages is no longer feasible, and we quite agree with them, in view of the many roentgenograms of the granite workers we have had the privilege of seeing with Dr. Russell. The nodulation or mottling is conspicuously absent as a rule. They are occasionally present, however, but in some of these instances the individuals had other dusty occupations before taking up granite cutting.

Incidence of Tuberculosis. Tuberculosis seems to be the final cause of death among the advanced silicotic granite workers. Russell and his associates divided the tuberculous cases into two groups. The first included the cases with advanced silicosis, and 71 were found during the period of 2¼ years' study. Of these, 54 died and 4 were not traced. The average age of incidence was forty-nine years and the average exposure period was twenty-eight years. This is a high incidence for the age period, and sufficient proof of the predisposing factor. The disease usually runs an acute course without periods of quiescence, and terminates fatally. Basal lesions are very frequent and almost impossible to interpret early by the roentgenogram. The second group included the earlier silicotic cases or those not showing the condition, and the infection resembled the usual type of the adult. Only 2 of the observed cases died, making 73 deaths from tuberculosis among 2,000 workers. Silicosis was not a proved factor in this second group. The age incidence averaged thirty-one years and the average period of exposure eight years.

The Slate Industry. A very few articles have appeared in the literature dealing with pneumoconiosis among slate workers. The most recent one was by Sutherland and Bryson.[114] They found evidences of fibrosis in 56 out of 120 workers examined. Those exposed to the most dust are the millmen, and 47 were among those examined. Definite silicosis was diagnosed in 14 of these workers, all of whom had over twenty years of service. Slate in the district of Wales in question contains 25 to 42 per cent of quartz. Those exposed to the dust seemed to exhibit an unduly high mortality from tuberculosis which occurred late in life. We have had the opportunity of examining a few slate workers, and have found slight evidences of fibrosis.

Iron Mining and Metallic Dusts. Siderosis has been recognized for a long time as an occupational form of pneumoconiosis. Iron dust may be inhaled from the ore mining, in industries using iron pigments, usually the oxide, and in metal grinding. Pneumoconiosis is quite commonly found among iron miners. We have examined roentgenograms of many of them and have observed varying degrees of fibrosis which was always ascribed to silica in the rock. It cannot be stated with certainty whether finely divided metallic particles are productive of pulmonary fibrosis or not, as in most studies of metallic mining and occupations in which metallic particles could gain entrance into the lungs there has been an admixture of fibrosis producing substances. There is now ample proof that finely divided metallic particles, especially iron, may be phagocyted and carried into

the lungs and even to other parts of the body. Whether the metal helps to cast the shadow or not is uncertain. Langguth,[64] quoted by Bohrod,[6] found 7.9 per cent dry weight of a siderotic lung to be iron oxide. This was small compared to the silica content. Carleton[8] exposed guinea pigs to large quantities of hematite and iron dust. The lungs showed no fibrosis. Iron in large amounts caused death from toxic effects, and bronchitis in smaller doses.

Collis and Goadby[15] have published a recent résumé of the iron ore mining industry in Great Britain from the standpoint of pneumoconiosis. The ores average 53 per cent of the oxide associated with limestone rock. Silica is present from 5 to 16 per cent, but mostly combined as silicates of aluminum and magnesium. Free silica is low and never over 7 per cent. Drills are used to a considerable extent. There is no apparent risk from tuberculosis. The drillers are the most frequent complainers of respiratory difficulties, but only after many years. The roentgenographic findings were described as some exaggeration of the root shadows and a generalized fine to medium mottling, more on the right side and below, and finer than is the rule in the usual silicosis cases. There was no diffuse generalized fibrosis. These findings would seem to compare with our own. In 3 autopsied cases dying from other causes much iron dust was found in the lungs and some general fibrosis unlike the usual fibrosis of silicosis. There is evident need of some comparison between the appearances of the roentgenograms of the lungs in this industry with those of many others such as asbestos workers, coal mining without rock dust and several others which differ essentially in roentgenographic appearances from the usual silicotic picture.

Bohrod[6] has reported 2 cases of interest. The first, a negro metal polisher, died with symptoms resembling late silicosis with tuberculosis. Iron granules were found in the liver, spleen and thoracic and pancreatic lymph nodes. In the consolidated areas and elsewhere in the lungs three kinds of pigment were found—extracellular black, extracellular brown giving no Prussian blue reaction and intracellular brown giving the reaction. The second case was a negro iron miner with unknown length of service. The roentgen diagnosis was advanced pulmonary tuberculosis. Subsequent autopsy showed advanced pneumoconiosis with massive fibrotic areas but no tuberculosis. Iron was found in the liver and spleen. The fibrotic pulmonary nodules showed large amounts of brown pigment. Iron pigment was also found elsewhere with the fibrous tissue. In both of these cases, most of the iron giving the Prussian blue reaction was intracellular, although there was much extracellular iron. It was suggested in explanation that in order to give the reaction the iron must be soluble which it probably was in the cells, but the extracellular iron was in an insoluble state with a protein. It was carried to other parts of the body in soluble form and was found there within the cells.

It seems appropriate just at this time to again call attention to the case reported by Gray and Tabb.[31] A roentgenogram was made of the chest of a woman because of a chest injury. This showed an appearance of the lungs like that of a diffuse nodular fibrosis, with dense spots 2 mm. in diameter. The patient had no respiratory symptoms. On searching for a cause for the appearance it was found that she had worked for three years in a printing establishment where cigarette packages were printed with a bronze pigment. The air was filled constantly with the fine powder. This pigment was known to contain copper, lead, aluminum and iron. Sometimes bronze powders of this kind contain zinc, tin and arsenic in addition.[19] This case brings up the question as to how much the great density of the nodular shadows in metal workers showing pneumoconiosis is due to the metal and how much to fibrosis.

The Pottery Industry. Chalicosis as an occupational disease has been recognized longer than almost any other industrial pulmonary hazard. Pottery workers are

likely to continue at their occupations from the time of apprenticeship to that of incapacity or death from some cause. A large percentage of them eventually show some evidences of pneumoconiosis, but the condition usually develops gradually, although it may assume the incapacitating form of advanced diffuse fibrosis. Landis[63] has summed up the situation very adequately in his statements to the effect that the pottery industry is a good risk with proper care and that the effects upon the lungs are most noticeable after forty years at work, and few workers remain at their trade after the age of sixty, being incapacitated by pneumoconiosis or tuberculosis.

The condition is due to the inhalation of silica. Nicholson states that the potters in England work with a mixture composed of flint, Cornish stone and clay which has a free silica content of 10 to 25 per cent, and that it takes twenty years to produce much fibrotic change in the lungs. Middleton[75] in describing the dangerous properties of some of the pottery dust states that a mixture of clay and ground flint is used in making earthenware, and that ground flint is dusted on the surfaces upon which china is placed for firing.

It seems evident that ground flint is the chief offender. It is particularly prevalent in the firing rooms. Sometimes sand is used instead of flint in making earthenware.

There has been a systematic investigation of the entire industry in many countries, especially Great Britain. It is natural that this industry should have its share of investigation because it is such an old one and the respiratory difficulties have been known for such a long time.

We have referred to the statements of several authors that a mixture of clay with siliceous rock may have a retarding effect upon the action of the silica and that admixtures of clay with silica in the material from which certain fire bricks are made may have a similar retarding action. These protective theories lack definite scientific proof, of course, and do not seem to work out in the pottery industry.

In our series of 58 potters previously reported,[90,91] 9 showed the first stage changes, 28 the second stage and 21 the third stage appearances. Some of this last group showed the most advanced diffuse fibrosis. One of the worst cases of silicosis we have ever observed was in a potter after forty-five years' occupation. The earliest appearance of nodulation was in a kiln man after only three years at work. The earliest case of advanced fibrosis of the terminal stage was after twenty-four years of service and the oldest case examined and found in this stage was after sixty-seven years at work. All roentgenological types of fibrosis are found, and the newer fibrosis classification we have suggested seems to be very well adapted to the condition in potters.

Holst, Kaplunova and Santotzkij[47] examined 282 porcelain workers of over fifteen years' occupation and found definite roentgen evidence of silicosis in 13.5 per cent and the condition was suspected in 24 per cent more. These authors state that tuberculosis was a frequent complication which ran a severe course when engrafted on silicosis, but apparently a milder one if contracted during the third stage.

We have had the opportunity of examining the roentgenograms of many individuals engaged in the making of porcelain insulators and other electrical devices made of this material and found several instances of pneumoconiosis among them.

The Cement Industry. Anyone familiar with the operation of a cement plant, or any individual who has passed by one during the working hours, cannot but realize that the employees are engaged in a very dusty occupation. Notwithstanding this fact, the cement industry does not seem to be a very hazardous one, mainly because of the comparatively harmless nature of the dust. The manufacture of cement is one of those industries in which several dusts of chemically and physically different characteristics are prevalent or intermixed, but they do not possess the widely different degrees of innocuousness or dan-

ger which are found in many other dusty industries, as in coal mining and pottery. The division of labor in respect to environments is grossly into the individuals exposed to cement, limestone, gypsum and coal dusts. In U. S. Public Health Bulletin No. 187[98] the free and combined silica in a cement plant investigated was found to be as follows:

	Total Silica	Free Silica
	per cent	per cent
Pack house	21.2	1.0
Crusher house, raw mill and stone house	16.8	6.5

Our experience with occasional examinations of the chests of cement workers during the past thirteen years has shown only minor degrees of fibrosis after long periods of work.

The most exhaustive work in connection with this industry has been carried out by Thompson, Brundage, Russell and Bloomfield[119] and the report of their investigations has been published in U. S. Public Health Bulletin No. 176, 1928. They estimated that 42,000 men were employed in 148 plants in this country. They selected a single plant for purposes of clinical and roentgenological study of the employees over a period of three years. They also investigated the various physical characteristics of the dusts. The greatest concentration of dust found was 92 million particles under 10 microns in size per cubic foot of air, but in other localities it ranged from 22 to 63 million. The analysis of the dusts has been mentioned above. The largest amount of silica was found in connection with the preparation of the stone. The percentages mentioned would seem to be within fairly safe limits, especially as compared to the granite industry, except that the cement plant dust may be found in the air in larger amounts. These authors found that the frequency of minor acute respiratory diseases was much greater than in non-dusty industries. Of the 570 men who received one or more complete physical examinations, 21, or 3.7 per cent, were diagnosed as either positive or suspected cases of pulmonary tuberculosis. The infection was active in only 2 of these, and in them it had developed prior to entering the industry. There was no evidence that exposure to this dust tended to render inactive lesions active. Chronic bronchitis was infrequent. Roentgenographic studies were made of 53 men in the different occupation groups, varying in service from six months to fifteen years. Of this number, 37 had worked over three years, and only 15 of these showed evidences of pneumoconiosis. Thompson and Brundage[117,118] in later summaries described the roentgenographic findings as a slight generalized fibrosis. Only one man had worked over twenty years and few over twelve years.

In our own group, examined in 1917, out of 20 workers, 15 showed slight to very definite nodulation. The earliest to show any changes was a cement packer who had worked for seven years. Of the 2 men longest at the work, one cement grinder showed slight evidences of fibrosis after eighteen years, and the other, a kiln room man, exhibited definite nodulation after nineteen years. The technique then employed was not such as would show the finer details now known to be essential in portraying such changes as early interstitial fibrosis.

Vitreous Enamel Painting. Siliceous dust in a very finely divided state is used in the making of vitreous enamel paints. These are usually applied by the spray method. It is obvious that hazards are encountered in the handling of the materials with which the paints are made as well as in their application by spraying. The spray method as applied to all kinds of paints has been investigated by the U. S. Public Health Service and by many state boards.

Siliceous paints are used extensively for the covering of many articles, such as reflectors, kitchen ware, metal signs, stoves, table tops and many others. We have had personal experience sufficient to warrant

the statement that the use of these paints is harmful without protection (Fig. 17).

We have had the opportunity to examine in consultation with Dr. H. F. Smyth[107,111] the roentgenograms of 83 individuals engaged in spray painting in Pennsylvania. Many of these roentgenograms were of such poor character as not to warrant their interpretation. Of the dependable ones, those of 10 individuals showed definite evidences of pneumoconiosis, and as early as two years.

Organic Dusts. It is generally conceded that organic dusts either do not produce pneumoconiosis or their effect is so slight as to be disregarded. Coal is not included among organic dusts.

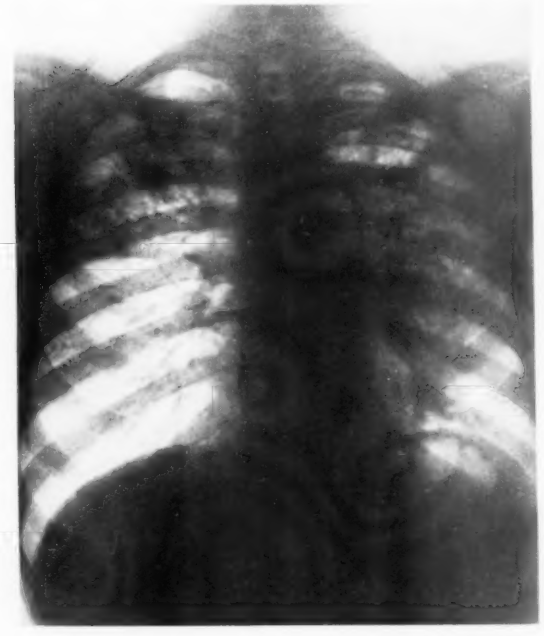


Fig. 16. Advanced pulmonary tuberculosis in worker in sand pulverizing plant. Male, negro, aged twenty-seven. Worked 7½ months. Dyspnea, cough, weakness and hemoptysis. The appearance is that of advanced tuberculosis rather than silicosis and especially because of the normal appearance of the right lower lobe. This and the short occupation time compared to the supposed latent period of silicosis would strongly suggest that tuberculosis was present before the individual started his work. This case cannot be used as proof that he was predisposed to the infection. He died a few months after the examination.

Fig. 17. Pneumoconiosis, with terminal diffuse fibrosis, massive consolidation type. This individual worked for four years as a foreman in a stove works with material from which vitreous enamel was made. He did not wear a mask as the other men did. He stopped work three years ago and has been getting worse since. An aneurysm was suspected clinically, but is not present. Roentgenogram loaned for illustration by Dr. Ralph S. Bromer.

CONCLUSIONS

1. The subject of pneumoconiosis has been reviewed from the standpoint of its etiology, its pathology and its roentgenographic appearances.

2. Pneumoconiosis is a more or less necessary risk of commercial development in the progress of civilization, but its progress and serious aspects may be lessened by certain preventive measures in most instances. Its incidence in many industries apparently cannot be altogether eliminated.

3. It has aroused widespread interest and has received a great amount of study during the past few years.

4. The roentgenological examination is the most important and accurate means of

detecting its presence, especially in early cases, of studying its progress and of determining its extent and severity. Rapidity of progression is easily determined by serial study.

5. Roentgenology will be employed more and more extensively as the necessity of study of workers in hazardous industries becomes realized and regulations for protection and compensation laws are adopted in this country. The roentgenologist must be experienced in his work and honest in the expression of his opinions.

6. It behooves the roentgenologist to become thoroughly familiar with the subject from every angle. The particular hazards of certain industries must be understood and the roentgenographic appearances more or less characteristic of some of them must be learned.

7. Roentgenographic appearances are the expressions of pathological changes, and to properly interpret them requires an intimate knowledge of the pathology of the condition. A résumé is given of the present exact knowledge of the pathology of pneumoconiosis based upon autopsy study and animal experimentation. Various theories advanced in explanation of some uncertain points are given brief consideration.

8. Various classifications of the degrees of progress of the condition are in use in different countries. Most of these have a clinical basis with which roentgenographic appearances must be made to conform. No one of them seems adequate or entirely satisfactory in its application to every dusty industry, especially from the standpoint of the roentgenologist. A new pathological-roentgenological classification is proposed, or at least offered as a suggestion.

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Publisher: CHARLES C. THOMAS, 220 East Monroe St., Springfield, Ill.

Thirty-third Annual Meeting: Detroit, Mich., 1932.

THE AMERICAN RADIUM SOCIETY

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Seventeenth Annual Meeting: 1932, to be announced.

Committee on Arrangements: G. E. PFAHLER, Chairman, 1321 Spruce St., Philadelphia, W. S. NEWCOMET, Philadelphia, W. H. SCHMIDT, Philadelphia, W. L. CLARK, Philadelphia, W. H. KRAEMER, Philadelphia, B. P. WIDMANN, Philadelphia.

EDITORIALS

THE JOURNAL'S TWENTY-FIFTH ANNIVERSARY

WE MAY be permitted a certain degree of pride in calling attention in this issue to the fact that October, 1931, marks the twenty-fifth year since the founding of the *American Journal of Roentgenology and Radium Therapy*. Special articles have been written pointing out the advances which have been made in the various fields of roentgenology and what the Journal has accomplished or tried to accomplish during the period of its existence.

Thirty-six years have passed since Roentgen's first announcement of the discovery which has in a large measure revolutionized medical diagnosis. Thirty-six years is a comparatively short time in the history of medicine but it is doubtful whether in the whole history of medicine such advancements have been made in any branch of the science as have been made in roentgenology. The first investigators in its application to the science of medicine were explorers in a new field. There were no old books from which they might learn; all was new and "where all is new, it is by no means easy to decide what is likely to prove ultimately true". It was therefore not unreasonable to expect that these early explorers might announce a discovery of great importance which by the subsequent charting of the areas explored would have to be altered somewhat from their first ideas or conceptions. It is singularly true, however, that most of the basic observations made by the early workers in this field have stood the test of time, with only a few modifications here and there as subsequent experience and a more widespread use of the new agent in diagnosis proved to be necessary. During all these years the application and progress of roentgenology have been recorded in the *American Journal of Roentgenology and Radium Therapy*.

It must have been with considerable boldness and temerity that the sponsors launched a new medical journal in the face of the splendid journals then in existence, but there was not in America at the time a representative journal devoting itself primarily to papers dealing with the application of roentgenology to medicine. It was the intent and purpose when the Journal was founded that its interest should be primarily in the clinical aspect of roentgenology. This policy was faithfully adhered to by Dr. Preston M. Hickey, one of the founders and its editor for ten years. To the untiring efforts of the capable editors who succeeded Dr. Hickey—Dr. J. T. Case, Dr. H. M. Imboden and Dr. A. C. Christie—the Journal owes the continued maintenance of the first-established policy and to the vision of those founders and editors the Journal owes its present position of importance in the medical world.

The twenty-fifth anniversary of the founding of the Journal offers an opportunity for rededication of its purpose to contribute in all ways toward the advancement of the science of roentgenology, believing as we do that any advancement in roentgenology and radium therapy will contribute toward the advancement of medicine in general.

THE ANNUAL MEETING

THE Thirty-second Annual Meeting of the American Roentgen Ray Society was held in Haddon Hall, Atlantic City from September 22 to 25, 1931. Atlantic City makes a most appropriate meeting place since it is accessible by all rail connections. The assembly hall itself, situated as it was on the thirteenth floor of the hotel, was quite cool and comfortable in spite of the humid weather which obtained through-

out most of the week. This floor also offered sufficient facilities for the scientific and commercial exhibits, and Dr. Jaches and his committee ought to be complimented on securing such ideal accommodations, and the Local Committee of Arrangements of which Dr. W. C. Wescott was chairman should be thanked for attending to all of the details on which the success of a meeting depends.

In addition to selecting an ideal place for the meeting, Dr. Jaches had arranged a most excellent program. From the first to the last paper the subjects were of interest, encompassing as they did practically every phase of roentgenology in its practical application both to diagnostic and therapeutic measures. The symposium on the roentgen and radium therapy of tumors of the oral and nasal cavities, of the tonsil, larynx and hypopharynx given by Dr. Elis Berven of the Radiumhemmet, Stockholm, Dr. Henri Coutard, of the Radium Institute of Paris and by Dr. Douglas Quick of the Memorial Hospital, New York City, was one of the outstanding features of the meeting, since it represented the work done and results obtained at three of the leading cancer centers of the world. Also of unusual importance were the papers on subjects of an experimental nature and the group of papers dealing with the physics of the roentgen ray.

At the opening of the meeting Dr. Pfahler did a very gracious thing in presenting to the Society a beautiful gavel made from rare old ivory buried during the glacial period and estimated to be perhaps a million years old. This distinctive and appropriate gift was accepted for the Society by the President, Dr. Moore.

The Caldwell Lecture, an annual event at the meetings, was delivered by Dr. Fedor Haenisch of Hamburg, Germany, who chose as his subject "Radiology as a Specialty." In this he discussed the importance of roentgenology and its relation to medicine and surgery and also the importance of maintaining roentgenology as a specialty. Dr. Haenisch's paper will be published in an early issue of the Journal and we cannot too strongly commend its careful reading by all those interested in roentgenology. President Jaches in his remarks at the opening of the meeting called attention to the fact that the second paragraph of the Society's constitution states that the purpose of the Society is to advance the science of roentgenology and to maintain it as a specialty. At the conclusion of the Caldwell Lecture there was an informal reception for the foreign guests.

On Wednesday evening a film was shown by Dr. Haenisch which dealt with numerous experiments conducted with inflammable and non-inflammable films. It demonstrated how useless are any storage precautions taken against the risk of fire in inflammable films and also that water has no value at all in putting out a fire once it has started, water proving, in fact, of a distinct disadvantage. In contradistinction to the danger of fire in inflammable films, the absolute safety of the non-inflammable films was demonstrated.

The annual banquet was held on Thursday evening with Dr. Pirie acting as toastmaster, which in itself would assure a pleasant evening to all those who attended. Added to this, however, were the delightful short talks by Dr. Haenisch and Dr. Percy Brown, and the main address of the evening by Dr. I. S. Ravdin of the University of Pennsylvania on "Radiology and Medical Science."

All in all, the Atlantic City meeting may be looked upon as having been a very satisfactory one, with its comprehensive program, the interest occasioned by the foreign guests, and the physical arrangements of the meeting and exhibit halls. Those in charge of the arrangements for the meeting wish through the Journal to express their thanks to the manager and the staff of Haddon Hall for their many courtesies and kindnesses shown to members and guests.

The following officers were elected for the coming year: President: Dr. Leopold Jaches; President-elect: Dr. William A. Evans; First Vice-President: Dr. B. R. Kirklin; Second Vice-President: Dr. Ross Golden; Secretary : Dr. Eugene P. Pendergrass; Treasurer: Dr. Edward L. Jenkinson; Member of the Executive Council: Dr. Merrill C. Sosman.

SOCIETY PROCEEDINGS, CORRESPONDENCE AND NEWS ITEMS

Items for this section solicited promptly after the events to which they refer.

MEETINGS OF ROENTGEN SOCIETIES*

United States of America

American Roentgen Ray Society
Secretary, Dr. E. P. Pendergrass, University Hospital, Philadelphia, Pa.
Thirty-third annual meeting: Detroit, Mich., 1932.

American College of Radiology
Secretary, Dr. Albert Soiland, 1407 S. Hope St., Los Angeles, Calif.
Annual Meeting: New Orleans, La., 1932.

Section on Radiology, American Medical Association
Secretary, Dr. G. W. Grier, Jenkins Arcade, Pittsburgh, Pa.
Annual meeting: New Orleans, La., May 9-13, 1932.

Radiological Society of North America
Secretary, Dr. I. S. Trostler, 812 Marshall Field Annex, Chicago, Ill.
Seventeenth annual session: Hotel Jefferson, St. Louis, Mo., Nov. 30–Dec. 4, 1931.

Radiological Section, Los Angeles County Medical Society
Secretary, Dr. John F. Chapman, 209 Professional Bldg., Pasadena Calif.
Meets on the third Wednesday of each month at the California Hospital.

Radiological Section, Southern Medical Association
Secretary, Dr. W. S. Lawrence, Medical Arts Bldg., Memphis, Tenn.

Brooklyn Roentgen Ray Society
Secretary, Dr. J. J. Masterson, 401-76th St., Brooklyn, N.Y.
Meets monthly on the first Tuesday from October to April.

Buffalo Radiological Society
Secretary-Treasurer, Dr. Joseph S. Gian-Franceschi, 610 Niagara St.
Meets second Monday of each month except during the summer months, the place of meeting to be selected by the host.

Chicago Roentgen Society
Secretary, Dr. George M. Landau, 660 Groveland Park.
Meeting second Thursday of each month October to May inclusive at Virginia Hotel.

Cleveland Radiological Society
Secretary, Dr. A. Srauss, 518 Medical Arts Bldg.
Meetings are held at 6:15 P.M. at the Cleveland Chamber of Commerce Club rooms on the fourth Monday of each month from October to April, inclusive.

Detroit Roentgen Ray and Radium Society
Secretary, Dr. E. R. Witwer, Harper Hospital.
Meets monthly on first Thursday from October to May, at Wayne County Medical Society Building.

Illinois Radiological Society
Secretary, Dr. Fauntleroy Flinn, 220 South Webster St., Decatur, Ill.
Regular meetings held quarterly.

Indiana Roentgen Society
Secretary, Dr. J. N. Collins, Indianapolis, Ind.
Annual meeting each February 22 in Indianapolis.

Milwaukee Roentgen Ray Society
Secretary, Dr. J. E. Habbe, 221 Wisconsin Ave., Milwaukee.
Meets first Friday in October, December, February and April.
Place of meeting designated by the president.

Minnesota Radiological Society
Secretary, Dr. L. G. Rigler, University Hospital, Minneapolis, Minn.
Next meeting: Rochester, Minn., October, 1931

New England Roentgen Ray Society
Secretary, Dr. Thomas R. Healy, 370 Marlboro St., Boston, Mass.
Meets monthly on third Friday, Boston Medical Library.

New York Roentgen Society
Secretary, Dr. J. Bennett Edwards, Englewood Hospital Englewood, N. J.
Meets monthly on third Monday, New York Academy of Medicine, at 8:30 P.M.

Central New York Roentgen Ray Society
Secretary, Dr. Robert C. Hall, 258 Genesee St., Utica, N.Y.
Three meetings a year—January, May and November.

Pennsylvania Radiological Society
Secretary, Dr. W. E. Reiley, Clearfield, Penna.
Next meeting, to be announced.

Philadelphia Roentgen Ray Society
Secretary, Dr. Karl Kornblum, 3400 Spruce St.
Meeting first Thursday of each month from October to May inclusive, at 8:15 p.m., in Thomson Hall, College of Physicians, 19 S. 22d St.

Rochester Roentgen Ray Society, Rochester, N. Y.
Secretary, Dr. Camp C. Thomas, 476 Lake Ave.
Meets monthly on the first Friday evening at 7:45 at the Rochester Medical Association Building.

St. Louis Roentgen Club
Secretary-Treasurer, Dr. E. W. Spinzig, 316 Metropolitan Bldg.
Meets first week of each month. Time and place of meetings designated by president.

Texas Radiological Society
Secretary-Treasurer, Dr. C. P. Harris, Houston, Texas.
Meets annually one day preceding the meeting of the Texas State Medical Association.

University of Michigan Roentgen Ray Society
Secretary, Dr. C. C. Taylor, University Hospital, Ann Arbor, Mich.
Meets first and third Wednesday evening of the month from October to June, at 8 o'clock in the amphitheatre of the University Hospital.

* Secretaries of societies not here listed are requested to send the necessary information to the Editor.

Virginia Roentgen Ray Club
Secretary, Dr. Wright Clarkson, 205 S. Sycamore St., Petersburg, Va.
Next meeting, to be announced.

Cuba

Sociedad Cubana de Radiologia y Fisioterapia
Secretary, Dr. Francisco Padron, Enrique Villuendas 64, Havana, Cuba. Meets monthly in Havana.

British Empire

British Institute of Radiology Incorporated with the Röntgen Society
Meets on the third Thursday of each month, from November to June inclusive, at 8:15 P.M., at 32 Welbeck St., London, W. 1., or as advertised.

Electro-Therapeutic Section of the Royal Society of Medicine (Confined to Medical Members)
Meets on the third Friday of each month during the winter at 8:30 P.M. at the Royal Society of Medicine, 1 Wimpole St., London, W. 1.

Section of Radiology and Medical Electricity, Australasian Medical Congress
Secretary, Dr. H. M. Cutler, 139 Macquarie St., Sydney, New South Wales.

Radiological Section of the Victorian Branch of the British Medical Association
Secretary, Dr. Colin Macdonald, Lister House, 61 Collins St., Melbourne, Australia.
Meets monthly at Melbourne during the winter.

Section on Radiology, Canadian Medical Association
Secretary, Dr. A. H. Rolph, 160 St. George St., Toronto, Ont.

Radiological Section, New Zealand British Medical Association
Secretary, Dr. P. C. Fenwick, The Hospital, Christchurch. Meets annually.

Continental Europe

Belgian Society of Roentgenology
Secretary, Dr. J. Boine, Avenue des Alliés, 134, Louvain (Belgium).
Meets monthly on second Sunday at d'Egmonds Palace, Brussels, except in the summertime.

Societe de Radiologie Médicale de France
Meets monthly on second Tuesday, except during months of August and September, 12 Rue de Seine, Paris.

Société Suisse de Radiologie (Schweizerische Röntgen-Gesellschaft)
Secretary for French language, Dr. A. Grosjean, La Chaux de Fonds.
Secretary for German language, Dr. Scheurer, Molzgasse, Biel.
Meets annually in different cities.

Société Francaise d'Electrothérapie et de Radiologie Médicale.
Meets monthly on fourth Tuesday, except during months of August and September, 12 Rue de Seine, Paris.

Association of German Roentgenologists and Radiologists in Czecho-Slovakia
Secretary, Dr. Walter Altschul, German University, Prague, 11/52.

Deutsche Röntgen-Gesellschaft (Gesellschaft für Röntgenkunde und Strahlenforschung)
Meets annually in April, alternating one year in Berlin, one year in some other German city. Meets in addition every two years with the Gesellschaft deutscher Naturforscher und Aerzte.
Permanent secretary, Professor Dr. Haenisch, Klopstockstrasse 10, Hamburg, Germany.

Süd- und Westdeutsche Röntgengesellschaft
Meets annually in different cities.

Nord- und Ostdeutsche Roentgengesellschaft
Meets annualy in different cities.

Dutch Society of Electrology and Roentgenology
Holds two meetings a year in Amsterdam, one in the Spring, and one in the Fall.

Societa Italiana Radiologia Medica
Secretary, Professor M. Ponzio, University of Turin, Turin.

Societatea Romana de Radiologie si Electrologie
Secretary, Dr. Nicolae Busila, 44 Elizabeta Blvd., Bucarest.
Meets second Monday in every month with the exception of July and August.

All-Russian Roentgen Ray Association, Leningrad, USSR in the State Institute of Roentgenology and Radiology, 6 Roentgen St.
Secretaries, Drs. S. A. Reinberg and S. G. Simonson.
Meets annually.

Leningrad Roentgen Ray Society
Secretaries, Drs. S. G. Simonson and G. A. Gusterin.
Meets monthly, first Monday at 8 o'clock, State Institute of Roentgenology and Radiology, Leningrad.

Moscow Roentgen Ray Society
Secretaries, Drs. L. L. Holst, A. W. Ssamygin and S. T. Konobejevsky.
Meets monthly on the first Monday at 8 o'clock, the place of meeting being selected by the Society.

Polish Society of Radiology
Secretary, Dr. Jan. Kochanowski, 45 Gornoslazka St., Warsaw. Meets annually.

Warsaw Section, Polish Society of Radiology
Secretary, Dr. B. Krynski, 11 Zielna St.
Meets once a month except in the summertime.

Scandinavian Roentgen Societies
The Scandinavian roentgen societies have formed a joint association called the Northern Association for Medical Radiology, meeting every second year in the different countries belonging to the Association. Each of the following societies, with exception of the Denmark Society, meets every second month except in the summertime:

Society of Medical Radiology of Sweden
Meets in Stockholm.

Society of Medical Radiology in Norway
Meets in Oslo.

Society of Medical Radiology in Denmark
Secretary, Dr. G. Biering, Copenhagen.
Meets on the second Wednesday of each month from October to July in Copenhagen, at 8 o'clock in the State Institute of Roentgenology.

Society of Medical Radiology in Finland
Meets in Helsingfors.

Vienna Society of Roentgenology
Secretary, Professor Holzknecht, Vienna, IX, General Hospital.
Meets first Tuesday each month, October to July.

Orient

Japan X-Ray Association
c/o Orthopedic Surgery, Tokyo Imperial University.
Meets annually in April.

Kinki Roentgen-Abend Society
Director, Dr. Prof. Taiga Saito, Ogawaoike Tyoto, Japan. Meets bi-monthly on third Sunday.

THE INTERNATIONAL CONGRESS

The Third International Congress of Radiology stands out vividly in the minds of those who were fortunate enough to attend. The Congress was held in Paris from July 26 to 31, 1931, under the Presidency of Dr. A. Béclère and the Honorary Presidency of Mme. Curie, the sessions taking place in the various amphitheatres of the Sorbonne. While the scientific programs began on Monday morning, July 27, the official opening took place on Monday afternoon in the main amphitheatre of the Sorbonne, at which the Minister of Public Health, M. Blaisot, presided. Dr. Béclère gave a very gracious address of welcome, after which followed one of the most impressive moments of the Congress—the tremendous ovation given Mme. Curie, a most modest and self-effacing woman in whom is embodied one of the world's greatest scientists. A number of the delegates chose this time to bestow upon Dr. Béclère signal marks of honor. Dr. J. M. W. Morison, delegate from the Royal Society of Medicine of London presented a diploma from the Royal Society; Dr. H. R. Schinz of Zurich, Switzerland, conferred upon Dr. Béclère a degree from the University of Zurich, and Dr. G. E. Pfahler, one of the delegates from the United States, made a presentation of an ivory gavel, with the following remarks: "I am commissioned to bring to you greetings from the radiological societies of America, namely, the American Roentgen Ray Society, the Radiological Society of North America, the American Radium Society, the American College of Radiology, and the Radiological Section of the American Medical Association. They have sent a gavel as an emblem of authority to you and your successors, as an expression of our spirit of cooperation. This gavel has been made from ancient ivory that was buried in the glaciers of Alaska during the glacial period and is therefore estimated by some to be about one million years old. We hope that this gavel may pass from president to president during at least one hundred years, and that it may serve as an emblem of peaceful authority at our international meetings."

Dr. Gösta Forssell, a delegate from Sweden, then presented another beautiful gavel to Dr. Béclère from the Swedish societies. Dr. Béclère responded appropriately to all these presentations.

It would be impossible to give in detail all the work of the Congress. The organization of details was excellent and those registering found that little time was consumed in obtaining all the literature dealing with the various phases of the Congress. There were over 1500 registrations but not all of these members were able to attend. The unfortunate financial situation in Germany just at the time of the Congress made it impractical for the German members to leave their country and thus Germany was represented by only about five radiologists instead of something over two hundred as would have been the case under normal circumstances. Their absence was regretted by every one.

There was an excellent exhibit of books and journals from all countries and one could see there many of the latest publications dealing with radiology.

The exhibition of apparatus was held at the Porte de Versailles some distance from the Sorbonne but ample opportunity was afforded for visiting it. This was a truly marvellous exhibit both in extent and in the quality of the exhibits. Some sixty-seven different exhibits were arranged in a large, well-lighted room so that they could be seen to the best advantage. One special feature was the number of protected therapy tubes on display by different manufacturers.

No account of the Paris meeting would be complete without mention of the various entertainments which the French had prepared for their guests. These included the soirée of welcome held at the Continental Hotel on Sunday evening, a reception for the official delegates at the Elysée by President Doumer on Monday afternoon, a gala performance of the Opera on Tuesday evening, the banquet at the Palais de la Mutu-

alité on Thursday evening, and a special performance of native dances at the Colonial Exposition on Friday evening.

Professor H. R. Schinz of the University of Zurich was elected President and Zurich, Switzerland, was chosen as the place of meeting of the Fourth International Congress of Radiology to be held in 1934.

Dr. Béclère and his able committee are to be congratulated upon their thorough arrangements of all the details connected with the Congress and the thanks of all those who attended should be extended to those responsible for a week so pleasant socially and profitable scientifically.

THIRD INTERNATIONAL CONFERENCE OF THE AMERICAN COLLEGE OF RADIOLOGY

In keeping with the established custom, the Executive Secretary of the College arranged for its regular International Conference to be held in Paris, France on July 29, 1931, at the Cercle Interallies. At no time in the transactions of the College does the first object of its constitution seem to be more truly achieved than during these international conferences.

Inasmuch as the President of the Third International Congress, Doctor Antoine Béclère, had been advanced to Honorary Fellowship in the College during its conference at Stockholm, Sweden, in 1928, and that the Secretary General of the Congress, Doctor Ledoux-Lebard would be honored with the same degree during this Conference in Paris, the Executive Secretary was able to enlist their very kind cooperation in selecting a time when no conflict would occur with other proceedings of the Congress, as well as in choosing a place where facilities were unsurpassable and the general environment ideal.

After the Fellows were all assembled, they were called to order by President Elect Soiland, who announced that the College would confer an Honorary Degree upon Doctor Rene Ledoux-Lebard of Paris, France and also upon Doctor Hans R. Schinz of Zurich, Switzerland.

In the absence of Dr. A. C. Christie, the President of the College, the Convocation was conducted by Dr. George E. Pfahler, who served as the first presiding officer of the College.

Following the Convocation, a few appropriate remarks of appreciation were given by Dr. Ledoux-Lebard, and Dr. Schinz also responded with a brief and appropriate statement, delivered in German and translated into English by Dr. Ledoux-Lebard.

Dr. Bundy Allen then addressed Dr. Béclère as President of the Third International Congress, complimenting him, his personal staff and associates on the wonderful program and the efficient and satisfactory manner in which it had been exe cuted. Dr. Allen also stated that as the President of the Radiological Society of North America, he wished to convey the approbation and good wishes of that organization and further that he wanted to take this opportunity to present to Dr. Béclère a personal gift, which he had ordered made for this special occasion. With a few fitting remarks Dr. Allen presented the gift, which consisted of a special hand made humidor, mounted with a suitably engraved silver plate.

President Elect Soiland then extended a hearty welcome to the Honorary Fellows, as guests of the College at luncheon, and requested the Fellows to repair to the Roof Garden following the luncheon where other business of the Conference would be conducted.

At this point Madame Marie Curie was received by the officers of the College and its Gold Medal was awarded to her by President Elect Soiland. The Honorary Degree was conferred by Past President Pfahler. The rare privilege of meeting this most modest and honored of all living scientists in the realm of radiology was an occasion that will never be erased from the memories of those who were fortunate enough to be present. Thirty-one Fellows of the College, representing ten of the

principal countries of the world were present.

B. H. Orndoff
Executive Secretary

THE SCIENTIFIC EXHIBIT

The Scientific Exhibit as arranged by Dr. Pendergrass and his committee for the Atlantic City meeting was on a par with the program as regards the range of subjects and the interest which it evoked among those present, and the Society owes much to the various members who contributed of their time and energy to the preparation of the exhibits. A brief description of each exhibit follows:

Dr. Paul A. Bishop, Pennsylvania Hospital, Philadelphia, had an exhibit which consisted of tracings of groups of epiphyseal separations and fractures in the region of the ankle joint, stressing the similarity of the anatomical lesions in the case of true fractures and epiphyseal separation-fractures, and classified according to the mechanism of production of the injury. This work was exceedingly interesting, and was something quite different from other types of scientific exhibits.

Dr. Charles W. Perkins, Norwalk, Conn., showed a few unusual cases.

Dr. Albert A. Rayle, Steiner Clinic for Cancer and Allied Diseases, Atlanta, Georgia, showed a number of roentgenograms of tumors of the bone, both benign and malignant, primary and secondary. This exhibit was excellent.

Dr. R. K. Ghormley, Dr. B. R. Kirklin and Dr. E. A. Brav of the Mayo Foundation for Medical Education and Research, Rochester, Minn., had an exhibit entitled "A Study of Surgical Specimens of the Knee-Joint." This exhibit comprised representative roentgenograms, gross specimens, history abstracts and photomicrographs in a series of 246 resections of the knee and 9 amputations. The object was to compare the roentgenologic and clinical interpretation of the cases with the actual specimens. The material showed that from a practical point of view it may be impossible to definitely differentiate roentgenologically between the tuberculous forms of arthritis of the knee and the nonspecific types. Whereas certain characteristics of the two varieties do exist, in the very early cases and in the cases of long duration they present similar roentgen appearances. Conclusions from this series definitely point towards the microscopic examination of tissue and guinea pig inoculation as the only dependable methods of diagnosis.

Another exhibit from the Mayo Clinic comprised a series of giant cell tumors of bone showing two roentgenologic types. The first variety has been accurately described by many observers. It is a central tumor, situated most often in the end of a long bone, and it exhibits trabeculae and expands the cortex but does not break through it. Other tumors of bone which may be confounded with this type of giant cell tumor are enchondromas and cysts of bone. In the second type of giant cell tumor trabeculation is conspicuously absent. The roentgenograms give evidence of homogeneous lysis of the affected area; the cortex is not only expanded but is dissolved wholly or in part, and the tumor projects into the soft tissues. In many cases the irregularly destroyed cortex has the appearance of a thin layer of melting ice. This variety of giant cell tumor might be mistaken for primary sarcoma or a massive metastatic growth. This exhibit supplemented a paper by B. R. Kirklin and C. M. Moore on "Benign Giant Cell Tumors."

Dr. W. F. Manges and Dr. L. H. Clerf, Jefferson Hospital, Philadelphia, had an exhibit on bronchial obstruction that showed roentgenograms of the various types of bronchial obstruction and artist's drawings of the appearance of the bronchus in the various types of bronchial obstruction.

Drs. Oscar V. Batson, Eugene P. Pendergrass and Vincent C. Johnson, University of Pennsylvania, Philadelphia, presented an exhibit on the temporal bone. This was an anatomic and roentgenologic study with the clinical applications.

Dr. Carleton B. Peirce, University Hospital, Ann Arbor, Mich., had an exhibit on giant cell bone tumor. In this exhibit there was a roentgenographic and photomicrographic representation of the methods and results of treatment.

Dr. Robert Drane, Savannah, Georgia, had a small exhibit on an unusual phytobezoar which caused intestinal obstruction.

Dr. Francis C. Grant, University and Graduate Hospitals, Philadelphia, had an excellent exhibit on ventriculography and encephalography demonstrating the disturbance in the ventricular outline in lesions of the brain, such as brain tumor, epilepsy, etc. This exhibit was presented in an interesting manner.

Dr. Elwood E. Downs and Dr. W. S. Hastings, Jeanes Hospital, Philadelphia, had an excellent exhibit on "Bone Metastases: With Photographs of the Primary Lesion." In this exhibit were shown 20 cases with bone metastases. These were selected from the roentgen-ray files without regard to the microscopic analysis of the primary tumor. A correlation of the types of bone metastasis with the microscopic description of the original neoplasm suggested that there existed a definite relationship between sclerosing or hyperplastic metastatic bone lesions and tumor desmoplasia. If the bone tumor excites marked desmoplastic reaction in its growth, its bone metastases show evidence of sclerosis. Conversely, anaplastic tumors with little tendency to desmoplasia produce destructive or osteolytic metastatic bone lesions. This exhibit represented a distinct advance in our knowledge of correlation of the secondary metastasis with the primary tumor and those who failed to avail themselves of the opportunity of studying this exhibit missed one of the most important exhibits at the meeting.

Dr. John R. Carty, Dr. John Remer, and Dr. C. V. Kilbane, Cornell Clinic, New York City, had an excellent exhibit which consisted of roentgenograms showing unusual thoracic lesions in which the necessity for careful correlation of the clinical and roentgenologic data was stressed.

They also showed a new type of roentgenoscopic room equipment in which it was possible to use an illuminating box for demonstration of roentgenograms without disturbing the accommodation of the eyes, and a chalk with which it was possible to demonstrate lesions to students as the chalk becomes fluorescent when exposed to ultraviolet light. This is described in detail in this number of the Journal in the Department of Technique.

Dr. Milton J. Geyman, Santa Barbara Cottage Hospital, Santa Barbara, Calif., had an exhibit entitled "Compression Technique: Its Application to the Roentgen Determination of Duodenal Lesions." A series of roentgenograms were shown as examples of normal and pathological duodenal caps under varying degrees of compression. Various types of ulcer niches were demonstrated. On most of the cases some views of the same cap made without compression were given for comparison. The types of cap in which compression technique offered no information not obtained by other methods were also shown. This exhibit was not only of importance as regards the information which it conveyed but the general make-up and display of the exhibit was excellent.

Dr. William G. Herrman and Dr. Frank Altschul, Monmouth Memorial Hospital, Fitkin Memorial Hospital, Asbury Park, N. J., had an excellent exhibit on various lung infections, but particularly those of the fusospirochetal infection of the lung.

Dr. William A. Evans, Detroit, Mich., had an excellent exhibit on vertebral body abnormalities, demonstrating a number of the usual and unusual diseases and injuries of the bone, and congenital malformations. This exhibit covered very thoroughly all the abnormalities, both congenital, occupational and constitutional and deformities resulting from injuries which one might encounter in a large series of examinations. This exhibit supplemented Dr. Evans' paper on the vertebral body.

Dr. David R. Bowen, Pennsylvania Hospital, Philadelphia, had an exhibit of a most ingenious precision apparatus for the roentgen examination of infants. In addition he demonstrated films and movies of the procedure.

Dr. Walter H. Ude, University of Minnesota, Minneapolis, Minn., had an excellent exhibit on "Roentgenologic Study in Early Lobar Pneumonia." The exhibit consisted of a series of anteroposterior and lateral films of the chests of patients who were studied in the early stages of lobar pneumonia. These films were all made at the bedside. They demonstrated the nature of the early consolidation as well as the distribution of the process in the various lobes of the lungs. So-called "central" or "hilum" pneumonia was shown to be in reality a posterior consolidation which follows the same cone-shaped distribution as in any other portion of the lung. In the stage of engorgement one may see only soft linear densities which are arranged in a triangular manner with the apex directed toward the hilum. Later this triangle becomes more homogeneous in density. The base of the triangle is always peripheral.

It may be seen from the cursory description of the scientific exhibits the wide range of subjects touched upon and the high quality of the exhibits. It is still to be regretted that sufficient time was not allowed for a more careful personal demonstration of the exhibits and it is to be hoped that at the future meetings ample provision will be made in the program for such demonstration.

The Committee on Awards for Scientific Exhibits, Dr. V. W. Archer, chairman, made the following report:

"The Committee on Awards wishes first to congratulate the numerous exhibitors on the general excellence of the exhibits, both in the actual material presented and the methods of its presentation.

"The award of a first place is a very difficult question, especially as there is no division into classes, such as clinical, purely research subjects, etc. Taking all factors into consideration, the Committee has decided that first place should be awarded to the exhibit of Dr. R. K. Ghormley, Dr. B. R. Kirklin and Dr. E. A. Brav, of the Mayo Clinic, because of the completeness, the technique, and the arrangement of material.

"Special mention should be made of the exhibit of Dr. E. E. Downs and Dr. W. S. Hastings, of Philadelphia; that of Dr. M. J. Geyman, of Santa Barbara; that of Dr. William A. Evans, of Detroit, and that of Dr. Oscar V. Batson, Dr. E. P. Pendergrass and Dr. V. C. Johnson, of Philadelphia."

THE COMMERCIAL EXHIBIT

One of the features of the annual meeting that always evokes much interest is the Commercial Exhibit and this year's exhibit was no exception to the rule. Practically all of the representative firms were represented and these annual meetings offer an easy survey of the advances which have been made in roentgenologic equipment and accessories during the year. The following had exhibits at the Atlantic City meeting: Bar-Ray Products, Inc., George W. Brady & Co., Buck X-Ograph Co., Eastman Kodak Co., General Electric X-Ray Co., Kelley-Koett Mfg. Co., Patterson Screen Co., Picker X-Ray Corp., Radon Co., Inc., Schering Corp., Charles C. Thomas, Westinghouse X-Ray Co., Inc., Winthrop Chemical Co., R. B. Davis Co., Standard X-Ray Co., Victoreen Instrument Co.

THE TEMPOROMANDIBULAR JOINT

To the Editor:

I was deeply interested in the article by Dr. Altschul—Studies of the Temporomandibular Joint—in the September issue of this Journal. He again called attention to this timely subject, to his excellent technique, and added to the literature several interesting cases, especially those of tuberculous infection. I wish to compliment him on this presentation.

In his introduction he calls attention to an article of mine on the same subject which was published in this Journal in July, 1929, and rather insistently criticizes me for omitting references to several techniques published in the German literature. He then describes four of these methods, all of them requiring that the patient's mouth be open. These had been considered by us and all discarded for the obvious reason he mentions and because of the changes due to joint movability which I mentioned, as were the several methods of oblique projection. So, after all, we agree thus far and I am guilty only of omission of enumeration.

I am guilty of overlooking Dr. Altschul's article which appeared in the *Fortschritte auf dem Gebiete der Röntgenstrahlen* in 1919. Had I been familiar with this I could have saved a great deal of tedious work by adopting his method. As to his 1927 article in the *American Journal of Roentgenology and Radium Therapy*, my paper had been written and was already in the hands of the Executive Council of the American Roentgen Ray Society, together with my application for membership, when his article appeared in print.

My paper was favorably acted upon at the 1927 meeting, was read by invitation at the 1928 meeting, and re-presented, this time for publication, thus accounting for its late appearace in July, 1929.

As to Dr. Altschul's criticisms of my method, they are just in part. There is some unavoidable overlapping which is, however, less confusing on the actual films than the printed reproduction would indicate, and is further minimized by stereoscopic observation, which I strongly urged. I have used Dr. Altschul's technique several times since 1927 and find it very satisfactory. In closing, I would like to add another word as to the value of the anteroposterior view.

Paul A. Bishop

Pennsylvania Hospital,
Philadelphia, Pa.

BOOK REVIEWS

Books Received Are Acknowledged under Heading: Books Received. This must be regarded as a sufficient return for the courtesy of the sender. Selections will be made for review in the interests of our readers as space permits.

Verlauf der wichtigsten Knochen- und Gelenkerkrankungen im Röntgenbilde: Eine anschauliche Prognostik. (Course of the most important Bone and Joint Diseases as Shown in the Roentgenogram.) Von Privatdozent Dr. med. Victor Hoffmann, Oberarzt der Chirurgischen Universitätsklinik im Augusta-Hospital zu Köln. With German and English text. Paper, price RM 66.00; bound, RM 69.80. Pp. 264, with 584 illustrations. Berlin: Julius Springer, 1931.

This volume is a departure from the usual stereotyped roentgenologic atlas in that it presents the most important bone and joint diseases, not by illustrations of isolated cases but by serial roentgenograms, depicting in detail the roentgenographic progress of the different diseases. Thus, for instance, in illustrating osteomyelitis of the femur, seven serial roentgenograms are employed, all from the same case. The author in his preface lays emphasis on this fact and feels that it is a definite help in obtaining a complete roentgenographic picture and knowledge of a disease. Because of this alone, the book is well worth careful study.

The more frequent diseases are given the greater prominence. But those that are less common such as osteitis fibrosa cystica and growth disturbances of the hip are also shown with considerable detail since they, as the author states, have a fundamental influence on medical teaching. Some diseases such as tuberculous arthritis of the hip joint merit in themselves a complete monograph and in these instances the author feels his limitations because of lack of space. The roentgenograms take precedence over the text, a necessity in the atlas type of book. It is printed with both German and English text.

The material is divided into seven chapters: the first on acute inflammations, hematogeneous, dental and traumatic osteomyelitis, and the specific and nonspecific arthritides. The last section includes cases of gonorrheal inflammation of the knee, hip and wrist joints, acute coxitis accompanied by high fever and systemic reaction, acute coxitis following tonsillitis and metastatic coxitis after septic abortion. The second chapter covers tuberculosis and congenital and acquired syphilis; the third, primary and secondary bone tumors including benign exostoses and chondromas. The fourth chapter includes metabolic and nutritional disturbances, among which are classed the various osteochondritides. The fifth chapter is entitled "chronic unspecific joint diseases" and under this are described progressive joint rheumatism, arthritis deformans and tabetic arthropathy, including a case of joint hemophilia. This classification and nomenclature are unlike those usually employed in American literature. The sixth chapter, on bone injuries, shows cases of healing fractures of bone, pseudoarthrosis, epiphyseal injuries, joint fractures, myositis ossificans, traumatic bone atrophy and ischemic muscular contraction. The last chapter illustrates bone transplantations and new joint formation, arthroplasty.

For the roentgenologist and student this book is extremely useful as a comprehensive résumé of the roentgenographic course of the more common diseases of bones and joints, but for those who seek for detail in certain diseases the information is lacking because of the limitation of space. Thus the prehemorrhagic stages of infantile scurvy are not shown, the various changes in rickets are not illustrated in detail, and cases of growth disturbance of the epiphyses of the hip, the anterior tubercle of the tibia, the tarsal scaphoid and the vertebrae are only shown in the chapter including the so-called osteochondritides. The classification and the nomenclature employed for bone tumors as well as those used for the various types of arthritis differ so greatly from the usual American terminology that for some readers a clear understanding and recognition of underlying pathologic changes may be difficult. The reproductions of the roentgenograms are excellent; they are clear with fine bone detail.

R. S. Bromer

Ergebnisse der medizinischen Strahlenforschung (Röntgendiagnostik, Röntgen-, Radium- und Lichttherapie). (Advances in Medical Radiology (Roentgen Diagnosis, Roentgen, Radium and Light

Therapy).) Volume V. Edited by H. Holfelder, Frankfurt a.M., H. Holthusen, Hamburg, O. Jüngling, Stuttgart, H. Martius, Göttingen and H. R. Schinz, Zürich. Paper, price 72 Marks; bound 74.50 Marks. Pp. 675, with 396 illustrations. Leipzig: Georg Thieme, 1931.

The fifth volume of this series of yearly offerings contains essays on practically all phases of radiology; i.e., physics, biology and diagnosis as well as roentgen and radium therapy. The reader will find, therefore, enough variety in the book to facilitate greatly his progress through its 675 pages.

H. Regelsberger (Erlangen) has chosen a problem which in spite of much attention has not been solved so far: the cascade stomach. Three characteristic signs are usually found as a syndrome: first, the cascade shape on the roentgenogram, the anacidity of the gastric juice and spastic constipation. The presence of hyperacidity usually speaks for an ulcer rather than carcinoma. Quite often the patients belong, psychologically speaking, to the labile group and there is reason to believe that the cascade stomach is a "vegetative stigma" (Bergmann).

A very careful experimental study of the small intestines in the roentgenogram is presented by H. Pansdorf (Frankfurt a.M.). He used mostly a barium suspension in water (3:4) given in fractional doses by mouth while the lowest part of the ileum was filled by an enema. The tonus of the intestines could be observed well by using stomach tubes for the introduction of the contrast medium after the intragastric and intestinal secretion had been withdrawn. The emptying time varied between five and seven and a half hours and after three to four hours the contrast medium usually reached the cecum. Atropine and pilocarpine produced characteristic changes in the outline and behavior of the small intestines as observed on the fluoroscopic screen. The absorption of fat was studied by the intraduodenal application of an iodopine emulsion; in normal cases it disappeared within three to four hours.

The two following essays are quite technical. O. Risse (Freiburg) discusses the physical foundations of photochemistry with particular consideration of light and roentgen rays and N. Wladimirowitsch Timofeeff-Ressovsky (Berlin) reviews the results of "radiation genetics" up to the present time. The latter is to my knowledge the most detailed and complete survey of this interesting field.

With the next contribution we enter the field of radiation therapy. W. Baensch (Leipzig) outlines first the anatomy and pathology of the hypophysis with a brief analysis of the clinical picture of the hypophyseal diseases. The roentgen diagnosis of tumors of the pituitary gland as well as the changes in the visus are also related. It appears that roentgen therapy is always indicated except in the case of a cyst, endothelioma or teratoma. If the vision decreases continuously, operation should be considered. For non-malignant tumors 500 r effective in the gland and for malignant neoplasms about 650 r effective in the growth are desirable. The saturation method of Pfahler is recommended. In dystrophia adiposogenitalis beneficial results have also been reported.

The possibilities of treating malignant struma are outlined by A. Hildebrandt (Frankfurt a.M.). In 21 cases of his own, surgery and roentgen therapy were employed, while 14 patients were irradiated only. The results of the combined treatment were considerably better (55.55 per cent and 22.2 per cent respectively) after five years. However, one must not forget that the irradiated cases included inoperable tumors. The treatment technique as practised at the Holfelder Institute is described. While malignant struma as a rule is a disease of middle and old age, it is interesting to know that the author observed a girl of seventeen years with this tumor.

From the Institute of Cancer Research (University of Berlin) appears a contribution by L. Halberstaedter and A. Simons, dealing with the radiation therapy of skin cancer. The implantation of thorium seeds is discussed at length and the authors conclude that today almost every skin cancer in the beginning stage can be cured by irradiation.

The last article in this group is written by H. R. Schinz and E. Uehlinger (Zürich). They discuss in detail the diagnosis, differential diagnosis and therapy of primary tumors and cysts of the skeleton. In the classification of bone tumors the work of Codman and Bloodgood is given full credit. It is emphasized that the diagnosis must be based on the correlation of facts furnished by anamnesis, clinical, roentgenological and histological examinations. The methods and results of treatment do not vary

materially from those familiar to all students of the literature on bone tumors.

Radium was also given a place in this volume through a chapter contributed by H. G. Zwerg (Konigsberg), who discusses the implantation of radon seeds in tumors of the skull, larynx, esophagus, bladder, prostate, rectum, gastro-intestinal tract, female genital organs and breast. Most American roentgenologists are undoubtedly familiar with the methods described in this article.

The last chapter of the book is most important to every investigator who desires to work with certain parts of the light spectrum. W. Friedrich and H. Schreiber (Berlin) offer a comprehensive review of the physical principles involved in work with the light spectrum.

All articles are well illustrated and to all contributions ample references are appended. Your reviewer feels justified in recommending this volume as a worth-while addition to your library.

Ernst A. Pohle

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DEPARTMENT OF TECHNIQUE

Department Editor: Robert B. Taft, 105 Rutledge Ave., Charleston, S. C.

A FLUORESCENT CHALK AND AN ILLUMINATOR FOR ROENTGENOGRAMS FOR THE ROENTGENOSCOPIC DARK ROOM

By JOHN R. CARTY, M.D.

Department of Roentgenology, Cornell Medical School

NEW YORK CITY

ROENTGENOSCOPIC demonstrations are often unsatisfactory because the demonstrator does not give the observer a satisfactory idea of what he wishes to demonstrate on the screen. Without a definite clear-cut pre-existing mental image, the faint screen shadow may be quite unintelligible to the onlooker. With this thought in mind, a blackboard using chalk fluorescing under the influence of ultraviolet radiation and a fluorescing viewing box for roentgenograms were devised.

The proper preparation of the eyes for screening is many times neglected owing to the press of work. Sometimes one is compelled to view a roentgenogram of a case about to be roentgenoscoped. This, of course, ruins the accommodation of the eyes and means that extra time has to be spent in the dark room. Moreover it would be of advantage if there could be a simultaneous viewing of the roentgenogram of a case and the screen examination. The advantages inherent in a blackboard which could be used without destroying accommodation are obvious.

The making of a suitable "chalk" presented considerable difficulty. A search of the technical literature gave but little information as to the actual composition of blackboard chalk or its manufacture. After many attempts a "chalk" was made and pressed to form, using anthracene as the principal ingredient. In addition to satisfactory fluorescing properties the chalk was of the proper consistency. It is possible to make a chalk which will fluoresce as long as fifteen minutes following cessation of exposure to the ultraviolet radiation.

The source of ultraviolet radiation was a mercury vapor bulb using a special glass which stopped most of the visible light. There should be some means of controlling the intensity of the radiation, such as a variable rheostat. The generator is best mounted on top of the blackboard, the rays being directed against the surface.

The chalk marks are brilliant and sharply delineated. An ordinary blackboard eraser cannot be used. The chalk must be washed off with a damp cloth. In visible radiation one cannot tell the difference from ordinary chalk.

Encouraged by the success of the chalk an ordinary 14″×17″ illuminating box was secured and a similar source of ultraviolet radiation was inserted instead of the usual tungsten bulb. The ground glass was covered on one side with a mixture of anthracene and a base which when melted flowed uniformly over the glass. There are several technical difficulties encountered in securing an even distribution of the mixture but this can be accomplished with care.

A 110 volt alternating current was used. There should be included a variable resistance in series. In this manner the intensity of illumination (fluorescence) can be varied at will. The light so produced is of a brilliant greenish hue similar to that of some roentgen screeens.

With the illumination at a maximum it was found that gazing did not appreciably interfere with accommodation, but actually seemed to increase it. If the light was allowed to fall directly on the roentgen screen some interference with the roentgen screen image was noted; but if the two were

side by side it was possible to roentgenoscope and keep the illuminator on at the same time.

Films of various parts of the body were placed before the illuminator. Heart and gastric detail was excellent. There was an unusual amount of detail visible in the lung fields, satisfactory for any but the most minute lesion. To our surprise, fracture lines were seen, even in a roentgenogram taken through a cast.

The various uses to which such an illuminator can be put are obvious. There is probably sufficient detail shown for the stereoscopic viewing of chests.

Summary. A fluorescing chalk and an illuminator for roentgenograms employing ultraviolet radiation are described. They should prove useful and convenient in the roentgenoscopic dark room.

I am indebted to Dr. H. C. Rentschler of the Westinghouse X-Ray Co. for invaluable help in working out the technical details and to Dr. C. V. Kilbane for his many suggestions in testing the apparatus.

A SIMPLE APPARATUS FOR PURIFYING RADON*

By G. H. HENDERSON, Ph. D., F.R.S.C.
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HALIFAX, N. S.

IN RADIUM therapy, radon is being used more and more widely in place of the radium salt because of its many advantages. When radium is used in this way some form of plant is necessary for pumping off, purifying and tubing the radon.

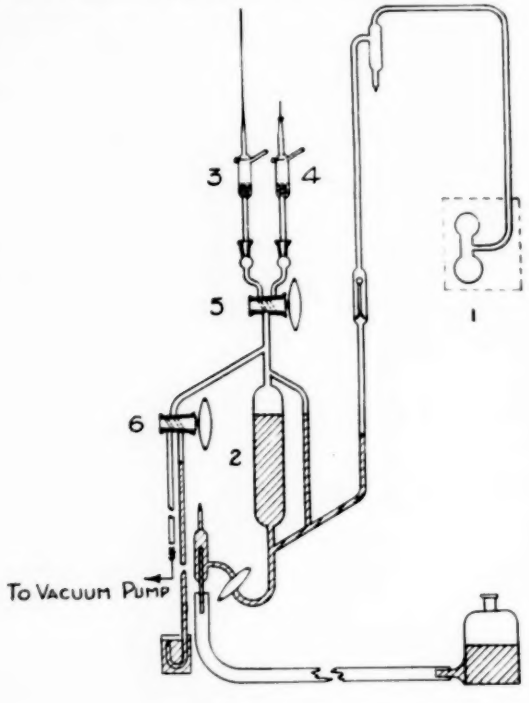

FIG. 1.

Many descriptions have been published of apparatus designed to fulfill this requirement. While serving their purpose, these plants have generally been very complicated with numerous bulbs, float valves and stopcocks (the latter alone usually numbering eight or more). A highly trained personnel is consequently required to operate the plant. The dangers of breakage and of clogging of valves and stopcocks are ever present in using glass apparatus. These dangers are multiplied in proportion as the apparatus is more complicated.

It seemed feasible to design a greatly simplified apparatus which would give equally good results. This apparatus should be cheaper, less liable to breakage and more easily manipulated than the usual type. These features are very desirable if the use of radon is to be extended so that small centers of population can enjoy its benefits.

Such an apparatus was developed in this laboratory with the aid of a grant from the National Research Council of Canada and a description of it published by Moran.[1] After the experimental plant set up in the Victoria General Hospital, Halifax, had been in use for three years with very satisfactory results, it became necessary to re-

* Also published in the *Canad. J. Research*, October, 1931.

[1] Moran, W. G. Two simple methods of purifying radium emanation. *Phil. Mag.*, 1929, 7, 399; also AM. J. ROENTGENOL. & RAD. THERAPY, 1929, 22, 147–149.

move it to another part of the hospital. Advantage of the opportunity was taken to rebuild the plant, incorporating small improvements and paying more attention to appearance. A short description of the plant follows. Many details are omitted which have already been sufficiently described in Moran's paper.

DESCRIPTION OF PLANT

The method of operation may be seen in Figure 1. The radon is pumped from the radium solution in the flask, 1, by the Toepler pump, 2, into the purifying unit, 3, which has been previously evacuated through the stopcock, 6. The impurities are removed by sparking and allowing the excess hydrogen to escape through a palladium tube, heated electrically from the outside. A little potassium hydroxide fused to the wall of the unit removes carbon dioxide and most of the water. When purification is complete the radon is simply pushed up into the capillary tube above and sealed off ready for use.

It will be seen that the number of stopcocks has been reduced to three, all of which can be cleaned without admitting air to the solution. There is but one large bulb and one float value.

It will be obvious to those familiar with the different types of radon plants that this simplification has been obtained by dispensing with the usual phosphorus pentoxide for drying the radon and by the use of palladium. Both of these features are original. The palladium method substitutes a clean physical purification for a chemical one involving frequent renewals of reagents and demanding great care lest the internal heating arrangements burn out. The use of pentoxide has always necessitated a second Toepler pump and numerous valves and stopcocks in order to transfer the purified radon into the capillary. In the present arrangement the radon is pushed straight through the purification unit into the capillary with a minimum of handling. Most of the water impurity is taken up by the potassium hydroxide. The remainder condenses on the walls of the unit as the mercury moves up. A visible layer of condensed water has never been observed on the top of the mercury in the capillary.

An alternative purifying unit, 4, is shown in Figure 1, which is useful, though not necessary, in preparing gold "seeds."

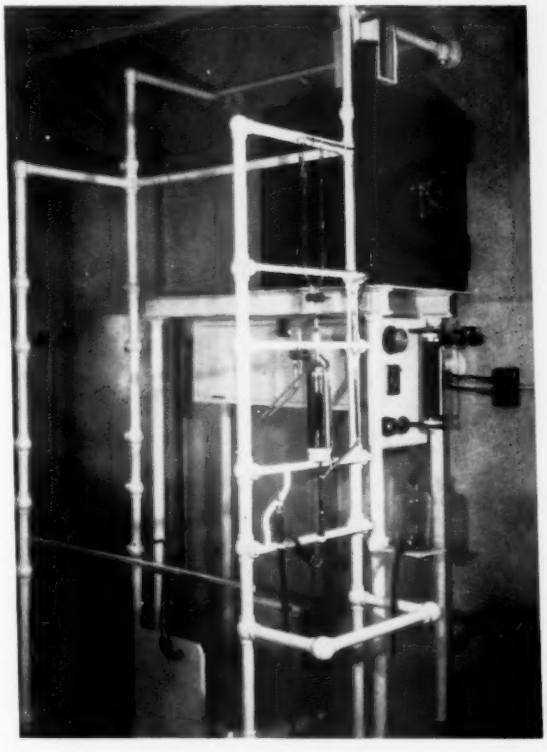

Fig. 2.

The tube leading from stopcock, 6, to the pneumatic trough is not necessary for the process described above, but is used for transferring radon elsewhere if required.

The completed plant is shown in the photograph (Fig. 2). The framework is made of $1\frac{1}{4}$ inch pipe using stock fittings and angle irons. Provision has been left for a duplicate installation. The radium solution is kept in a commercial safe and is surrounded by over half a ton of lead bricks, giving an average protective thickness of more than 5 inches. The tube leading to the Toepler pump is protected by lead tubing of $\frac{3}{4}$ of an inch wall thickness.

The safe and contents are kept cooler than the room by circulating water, thus preventing distillation of the solution into the pump.

The purification unit is evacuated through stopcock, 6, by a Hyvac pump. With an occasional cleaning this pump has given a satisfactory vacuum for over three years.

All glass parts of the apparatus are made of Gundlach glass. Attention is drawn to the shape of the flask containing the solution. The upper bulb is for the protection of the solution in case of an inrush of mercury. Against this remote contingency three safeguards have already been provided: (1) a float valve, (2) a trap and (3) by having the tube leading to the solution rise to more than barometric height above the top of the Toepler pump. Should mercury reach the flask in spite of these safeguards, the solution would be displaced into the upper bulb of the flask and held safely there. The contingency, as already remarked, is remote but is present in all types of radon plants.

PERFORMANCE

This type of apparatus has given satisfactory results for over three years. The radon can be readily concentrated to 100 millicuries per cubic millimeter. This would mean, for instance, 10 mc. in a gold "seed" 5 mm. long and 0.15 mm. internal diameter. The apparatus works quickly, the actual purification taking from two to five minutes.

It might be thought that trouble would arise since no particular pains are taken to remove water vapor. In particular, there might be fear of occasional blowouts in sealing off the capillary. No such trouble has developed. Only three blowouts have occurred since the plant was set up, all caused by attempting to seal off tubes at too high gas pressures. There cannot be more water vapor in the compressed radon than the amount corresponding to the water vapor pressure at room temperature.

The alternative method of purifying by hot copper oxide described by Moran has been given up and the palladium tube method used exclusively. The latter is a purely physical method which is indefinitely reproducible and does not involve any danger of clogging the capillary with particles of loose reagent.

The amount of radium in solution in this apparatus in the Victoria General Hospital is 200 mg. There seems to be no reason why it should not work equally well with larger quantities of radium.

In conclusion, I wish to thank Mr. S. T. Alvey for the skill and care with which he has constructed the plant.

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ABSTRACTS OF ROENTGEN AND RADIUM LITERATURE

ROENTGEN DIAGNOSIS

SKELETAL SYSTEM

Hartman, Joyce I., and Friedman, Eugene. The clinical and roentgenologic manifestations of scurvy in a seven year old child. *Am. J. Dis. Child.*, Feb., 1931, *41*, 337–343.

Poupart, Moeller and Barlow described infantile scurvy but there have been few cases of the disease recognized in late childhood. Fraenkel (1903) reported the condition in a child aged seven years; Tobler (1918) recognized and treated 200 patients in an asylum for refugee children in Vienna, but in both instances the roentgenographic studies were incomplete. The authors present their case to help bridge the gap in knowledge between infantile and adult scurvy, and to show roentgenographic differences between scurvy in the infant and that in the older child. Their patient was a boy of seven who was obviously an idiot. His mother stated the child's diet consisted of 8 to 10 ounces of pasteurized milk, purchased from the "corner" grocery, three times a day, oatmeal or farina three times a day and bread without butter frequently. No vegetables or meat had been given because the child could not chew. She claimed that she had given some orange juice, but admitted that the child had had very little. The probable amount could not be ascertained.

The first series of roentgenograms of the left lower extremity showed an absence of trabeculation of the bone in the shaft of the femur and the epiphyses at the knee. The epiphyseal center was separated and displaced laterally. There was a slight increase in the amount of calcification at the cortical border of the diaphysoepiphyseal line. The epiphyseal line was sharply defined. Both epiphyseal centers were surrounded by delicate lines of increased calcification. The tibia and the fibula also showed a lack of trabeculation. Six days after the first examination, the right leg in the region of the knee became swollen and seemed much more painful than it had been on admission. There was no crepitus. Roentgenograms of the right leg showed an almost identical appearance with that of the left. Roentgenograms of the upper extremities showed no changes. Three weeks afterward, antiscorbutic treatment having been instituted in the meanwhile, roentgenograms showed the shafts of both femurs surrounded by homogeneous, wide shadows of increased calcification which extended from the epiphyseal lines to the region of the lesser trochanters.

The previously separated epiphyseal centers showed a fairly good alignment. In six weeks the epiphyses appeared firmly united, the calcifications about the shafts were about the same, the trabeculations were indistinct. Eight months later, the condition of the femora was about the same as on the previous examination, with the exception that the trabeculations were more distinct.

This case differed from infantile scurvy in that the usual broadened and dense zone of temporary calcification at the diaphyseal extremities and the rarefied zone immediately behind it, the framework marrow zone were absent. The extent of the subperiosteal hemorrhages and the epiphyseal separations in the authors' case was remarkable. Their patient showed the ground glass appearance of the shafts and the rings of increased density around the epiphyseal centers of the femora and tibiae just as in infantile scurvy.

Scurvy in childhood is a rare disease in this country and probably occurs only under the most unusual circumstances, such as were present in the authors' case. The patient was unable to masticate ordinary foods, including vegetables and meats, and was given a very limited diet, which was incomplete in regard to the vitamin content because of the low intelligence of the parents. Such a combination of factors necessary for the development of the disease is unusual.—*R. S. Bromer.*

Geipel, P. Zur Kenntnis der Spina bifida des Atlas. (The knowledge of spina bifida of the atlas.) *Fortschr. a. d. Geb. d. Roentgenstrahlen*, Nov., 1930, *42*, 583–589.

Nine cases of spina bifida of the atlas were found in a total of 260 macerated vertebral columns, an incidence of 3.5 per cent. The separation varied from a simple fissure to a cleft 6 mm. wide, and was localized mostly 2 to 3 mm. to the left of the midline. The condition has not as yet been observed roentgenologically in the living.—*T. Leucutia.*

Meyerding, H. W. Spondylolisthesis. *J. Bone & Joint Surg.*, Jan., 1931, *13*, 39–48.

Subluxation of the lumbar spine, "spondylolisthesis," is of interest as either a congenital or traumatic factor in the etiology of pain in the lower back and of deformity. Previous to 1900 most of the cases were reported by obstetricians, but with the use of the roentgen ray and careful examination of the spinal column the condition has been found with equal or even greater frequency in men than in women.

Trauma is significant as a cause of spondylolithesis and obesity, pregnancy, and occupational strain may also produce it, usually in a gradual fashion. Congenital defects, variations of the fifth lumbar vertebra and the lumbosacral joint, are often noted during the examination. Sudden severe injury may instantly cause subluxation with immediate disability and pain. With the present methods of roentgen examination congenital defects are easily recognized.

Meyerding analyzes a series of 121 cases from the Mayo Clinic. His paper is well illustrated with tracings and roentgenograms. Using a series of tracings (drawn from roentgenograms) he illustrates the variations of the lumbosacral joint showing that the lumbosacral angle varies fully 60 degrees; the sacral articulation may be rounded and the fifth lumbar concave. Forward displacement varies from slight to complete. Separation of the laminae is common. His operative treatment consists in fusion by double massive grafts, multiple chips, and cancellous bone including the third, fourth and fifth lumbar vertebrae and the sacrum.

From his study he finds that in his series about 62 per cent of the cases were men; trauma appeared to be a significant factor in the etiology, although congenital defects and apparent instability of the lumbosacral joints are additional factors. The condition may be partial or complete with variations of the lumbosacral angle. Symptoms are mainly backache; if onset is sudden, severe trauma is usually associated. The absence of symptoms with the patient at rest, and the aggravation of pain on exertion are characteristic. Shortening of the torso, lordosis, and a broadened appearance of the pelvis are common. Prominence of the upper posterior border of the sacrum is present to a varying degree. Depression due to displacement of the fifth lumbar vertebra with local tenderness is common. The anteroposterior diameter of the pelvis is lessened, thus narrowing the birth canal. The neurologic signs are usually paresis and modified sensation, limited commonly to the fifth lumbar vertebra and the first sacral segment. Complete paraplegia at this level is impossible unless severe trauma has injured the cord at a higher level. Pain and paresthesia over the saddle area may be present.

Stereoscopic or lateral roentgenograms are best, as the anteroposterior roentgenograms may not disclose the lesion. In addition to operative treatment, patients are treated by casts, braces, and corsets.—*R. S. Bromer.*

Böhler, Lorenz. Diagnosis, pathology, and treatment of fractures of the os calcis. *J. Bone & Joint Surg.*, Jan., 1931, *13*, 75–89.

The author presents the methods of treatment of fractures of the os calcis which are in vogue in an accident hospital in Vienna which was founded five years ago. He considers fracture of the os calcis as among the most difficult, from the viewpoint of treatment and end-results. The diagnosis is easy but nevertheless is often overlooked. The diagnostic points are, the history of a vertical fall from a height of 1 to 5 meters, inability of weight-bearing, the broadening and swelling of the region about the heel, and the hematoma which extends towards the sole of the foot—a sign which is never seen in malleolar fractures. The most important sign, however, is the pressure pain, strictly limited to the os calcis.

The fracture of the os calcis occurs in a typical manner. The lateral wall is broken off, while on the medial side the posterior portion of the surface articulating with the astragalus is shorn off, and is sometimes driven downward. Two fractures are thus produced in the sagittal plane: the one involves the lateral wall of the bone, the other runs from the medial side obliquely forward. The medial fragment, containing the sustentaculum tali, usually remains in place; while the middle portion of the bone and the lateral fragment are displaced laterally and apear as a hard bony mass below the lateral malleolus. Occasionally the tuberosity of the os calcis also is divided into several longitudinal fragments. The os calcis appears thereby greatly broadened and shortened. In the lateral roentgenogram one sees several fracture lines in frontal or oblique planes, which are produced principally by bending or sheering stress.

Normally, there exists, between the upper contour of the tuberosity of the os calcis and the line uniting the highest point of the anterior process with the highest point of the posterior articular surface, an angle of 30 to 35 degrees. Böhler calls this the "tuber-joint angle." In fractures of the os calcis, this angle becomes smaller, straight, or even reversed, and the displacement is maintained by muscle pull. He illustrates this angle by means of roentgenograms.

In treating these fractures, Böhler aims at reposition with correction of the axial deviation, of the flattening and the shortening of the bone. Unlike other fractures which are reduced immediately, in fractures of the os calcis, an interval of six to ten days is allowed to elapse in order to allow the swelling to disappear before reduction is attempted. This is carried out under lumbar anesthesia. His method of treatment is described in great detail. With restoration of the form of the crushed os calcis in the manner he describes, complete functional ability of the foot is observed after four to eight months, depending upon the age of the patient and the degree of comminution of the bone. He has treated more than one hundred fresh fractures with his method.

In the estimate of disability, immediate diagnosis is of importance not only for treatment but for evaluation of the injury as well. In lateral roentgenograms, old fractures appear apparently normal and the structure of the bone continuous, but the tuber-joint angle is smaller or has disappeared or is even reversed. This latter point alone makes the diagnosis of fracture of the os calcis certain. In ordinary flat-foot the axis of the astragalus is slightly deflected plantarwards; in fracture of the os calcis, the astragalus stands horizontally. The axial roentgenogram showing shortening and broadening of the bone is still more certain in the diagnosis of fracture. Thus two planes, the axial and lateral are necessary in the roentgen examination. The lack of the axial plane roentgenogram has resulted in the denial of compensation because the loss of pronation and supination and the existing flat-foot were considered signs of inflammation and not of previous injury.—*R. S. Bromer.*

Legal, Wilhelm. Das erste Tarsometatarsalgelenk beim Hallux valgus im Röntgenbild. (The roentgen appearance of the first tarsometatarsal articulation in hallux valgus.) *Fortschr. a. d. Geb. d. Röntgenstrahlen*, Jan., 1931, *43*, 100–103.

The author examined the roentgenograms of 68 cases of hallux valgus and found that there are no criteria which might differentiate a normal tarsometatarsal joint from that observed in hallux valgus.

Not infrequently the hallux vulgus is asso-

ciated with arthritis deformans of the first tarsometatarsal articulation, this being the result either of mechanical irritation or of rheumatic changes.—*T. Leucutia.*

Kugelmass, I. Newton, and Berg, Richard N. Ossification. I. Callus formation and calcification. *Am. J. Dis. Child.*, Feb., 1931, *41*, 236–248.

Ossification is a local transformation of fibrous tissue into solid bone, the constituents of which are from the blood. The mechanism of this local chemical change is not understood, and so the problems of normal and pathological calcification have been approached essentially from the systemic standpoint. Such a procedure, the authors state, limits the understanding of the chemical pathology of bone, and so they initiated some studies on the local chemical processes involved in calcification.

They discuss the mechanism of bone repair, and also the nature of delayed union. The systemic causes of delayed union are: (1) focal infection, (2) thyroid disease, (3) multiple fractures and (4) debility. The local causes of non-union are: (1) inadequate reduction, (2) inadequate fixation, (3) circulatory interference, (4) interposition of muscle and (5) repeated reduction. Experimental fractures were induced on rabbits and revealed that, all other conditions remaining constant, the amount of available fibrous tissue is directly proportional to the degree and rate of calcification. Bone repair involves: (1) the approximation of the fractured ends; (2) their initial union with the network of fibrous tissue, and (3) the transformation of this fibrous network by solid calcium salts.

Their conclusions follow:

The greater the local formation of fibrous tissue, the greater was the amount and degree of calcification, all other conditions remaining the same.

The blood calcium tends to be higher and the phosphate lower in the course of normal bone repair, and the more rapid the rate of calcification the more marked is this alteration in the calcium and phosphate content of the blood.

Injection of an alkaline solution of trypsin, at the site of fracture to produce fibrous dissolution, markedly retarded the union of bones in comparison with that in the control series.

Injection of a solution of tissue fibrinogen in animals at the site of fracture, to stimulate increased callus formation, markedly accelerated the union of bones in comparison with that in the control series.

The maintenance of animals with experimentally induced fractures on a diet high in protein, to increase the blood-clotting factors, produced no local effect in bone repair as compared with the control series.

Ossification is a local transformation of fibrous tissue into bone, the constituents of which are derived from the blood. Bone repair is a local rather than a systemic process, and union may therefore be induced or accelerated by local therapeutic measures.—*R. S. Bromer.*

Speed, Kellogg. Blood serum calcium in relation to the healing of fractures. *J. Bone & Joint Surg.*, Jan., 1931, *13*, 58–67.

After studying blood serum calcium and phosphorus in a consecutive series of patients with fracture and failing to find any great degree of abnormality or correlation of the blood serum findings to the clinical course of union or non-union, experimental work was undertaken by Speed to test out the previous conclusions of Peterson. Peterson's work and his statement that a blood serum calcium-phosphorus product of 30 or lower leads to non-union after fracture have been generally accepted, liberally quoted and literally interpreted.

In Speed's work, three types of experimental fractures on dogs were performed.

1. Fractures during a period of low blood phosphorus, little calcium lowering, produced by deficient diet.

2. Fractures during a period of high blood calcium produced by feeding large amounts of calcium lactate three times a day.

3. Fractures during a period of low blood calcium produced by parathyroidectomy, which brought about in time a high blood phosphorus.

The animals in the first series failed to give clinical evidence of delay in bony union after experimental fracture when compared to a normal (and often litter mate) control. The roentgen findings were likewise equivalent to the normal, and the microscopic findings were those of normal bone healing.

In the second series, the animals failed to show any clinical delay or acceleration of bone healing after experimental fracture, with the same controls, and the roentgen and histologic findings were likewise normal.

In the third series, the animals showed a de-

cided delay in bone healing after experimental fracture when compared with the normal and with similar controls as the other two series. The roentgen and microscopic findings confirmed this delay in bone healing.

In addition, Speed made several hundred blood determinations on fracture patients which seemed to show that:

1. Immediately after fracture, blood phosphorus is low.
2. The blood calcium is normal.
3. The average admission calcium-phosphorus product is within normal limits—36 to 40.
4. Within twenty-four hours after any major fracture the blood serum phosphorus content rises and remains high, coming down slowly, possibly varying with the degree of disability—three to five weeks. Increased muscular exercise may hasten this.
5. The blood serum calcium content remains about stationary.
6. Diet has little or no effect on either calcium or phosphorus content of the peripheral blood.
7. After any operative procedure, there is an almost immediate rise in blood serum phosphorus followed by a rapid fall to normal.

In consequence of his experiments and many observations on humans, Speed believes that an estimation of blood serum calcium and phosphorus is valueless from a prognostic standpoint; that attempts to change the blood serum content of these two elements is valueless as a sure means of obtaining union after fracture, and that no numerical product of the two elements, gauged by the amount of them present per 100 c.c. of blood serum can be used as a criterion of prognosis.—*R. S. Bromer.*

GENERAL

Muzii, Mario. Considerazioni su 4600 esami radiologici esequiti in sei anni. (Forty-six hundred roentgen examinations made in six years.) *Arch. di radiol.*, Nov.–Dec., 1930, *6*, 1143–1165.

Of these examinations 1075 were of the locomotor system, 1084 of the respiratory system, 1964 of the digestive tract, 249 of the urinary tract, 59 of the circulatory system, 10 of the female genitalia, 127 of the skull, 23 of the teeth and 27 were examinations for foreign bodies. Tables are given showing the numbers of cases for the various conditions of these systems and details of technique given.

Only 145 cases were treated. Skin epitheliomas were always cured if they were superficial and had not extended very deep; the results were unsuccessful if they had invaded bone or cartilage. Treatment of gland metastases of epitheliomas of the lips and breast was a failure. In 3 cases of postoperative prophylactic irradiation for carcinoma of the breast the patients died of metastases in the liver. In inoperable carcinoma of the uterus there was temporary improvement of the pain. In osteosarcoma there was not even temporary benefit. In malignant lymphogranuloma and myeloid leukemia there were the usual results, that is, disappearance of the enormous tumors and enlargement of the spleen with improvement and return to normal of the leucocyte formula and apparent cure for varying period of time up to as long as three years and then recurrence. In one case of tumor of the hypophysis there was great improvement and the patient is still alive 2 1/2 years after the beginning of treatment; irradiations are being given every two or three months. Two cases of permanent castration for fibromyoma and 3 of temporary castration for hemorrhagic endometritis were completely successful. The results were good in tuberculous lymphoma and completely successful in keloid and large acuminate condylomata; they were almost entirely negative in spina ventosa, lupus and malarial spleen. There was no improvement in 2 cases of insular sclerosis. Perfect hemostasis was brought about in a hemophiliac with a lacerated contused wound of the lower lip. There was marked improvement and cure in Basedow's disease. The results were perfect in all cases of tinea favosa and sycosis of the beard.

In general, the author's results were about the same as those usually reported in the literature.—*Audrey G. Morgan.*

ROENTGEN AND RADIUM THERAPY

Cramer, H. Erfahrungen mit der kombinierten Isaminblau Strahlentherapie. (Experience with combined isamin-blue-radiotherapy.) *Strahlentherapie*, Sept. 27, 1930, *38*, 123–140.

The author has had excellent results from preliminary treatment with isamin-blue followed by intense roentgen therapy. Particu-

larly in large tumors at sites that are not favorable for irradiation, roentgen therapy can be carried out more intensely and with less toxic effect after preliminary mobilization of the absorptive forces. In illustration he describes and gives roentgenograms of cases of bronchial carcinoma and one of an enormous tumor of the scrotum. Bronchial carcinoma is an extremely difficult condition to treat and his results with this treatment have been surprisingly good. The cases have not been under treatment long enough to say what the late results will be. The isamin-blue treatment is only to be recommended as a supplement to roentgen therapy, not as an independent treatment.—*Audrey G. Morgan.*

Gál, Felix. Die Entwicklung der gynakologischen Röentgenbehandlung während der letzten 10 Jahre in der II Universitats-Frauenklinik Budapest. (The development of gynecological roentgen treatment during the last ten years at the 2d University Gynecological Clinic at Budapest.) *Strahlentherapie*, Sept. 2, 1930, *37*, 623–641.

At first roentgen treatment was only used for castration in chronic hemorrhage but now it is used for climacteric metropathy, myoma of the uterus, hemorrhage from inflammation of the adnexa, irradiation of the spleen or thyroid for juvenile hemorrhage, carcinoma, sarcoma stimulant irradiation for ovarian hypofunction, pruritus vulvae, condylomata acuminata, osteomalacia, peritoneal tuberculosis and irradiation of the thyroid for signs of loss of ovarian function.

The most hopeful field for roentgen therapy is climacteric metropathy as 100 per cent of these patients are cured. The treatment consists of castration which has no bad effect and frees the patient from the irregular hemorrhages; 582 cases have been treated. Roentgen treatment for myoma has been successful in most of the 851 cases in which it has been used. Success depends on proper selection of the cases. Roentgen treatment is indicated in women who have reached the climacteric, in cases complicated by heart, kidney or lung disease and in anemic, obese individuals. In carcinoma, the author believes operation should be performed only in cases which can be operated on without danger and others should be irradiated, as cancer is a general and not a local disease and surgery is not very hopeful. The author has demonstrated 20 inoperable cases cured for more than five years; 2 cases have been cured for seventeen and fifteen years respectively. Experience has shown that results are better with doses that are not too large. They generally give somewhat less than the carcinoma dose. Sarcoma of the female genitalia is perhaps even more malignant than carcinoma. Three inoperable patients given irradiation are still alive after more than five years.

Pruritus vulvae is due to different causes and the results of irradiation therefore differ. The results are best in the cases caused by discharge and eczema and the so-called idiopathic pruritus. In cases caused by diabetes, severe neurasthenia and loss of ovarian function irradiation is generally not successful. In some cases cure was permanent and in others temporary. Irradiation is worth trying if other remedies fail.

Condylomata acuminata can be cured by two or three roentgen irradiations. Four cases of osteomalacia were irradiated. Two of the patients were in the climacteric. Irradiation of the ovaries brought about complete cure in only 1 case. In the other 3 cases the pain stopped for awhile and then reappeared. On irradiation of the thyroid the patients were permanently cured. Irradiation of the spleen proved very successful in stopping irregular hemorrhage. Stimulant irradiation of the ovaries also proved successful in amenorrhea. Irregular hemorrhage in young women was also controlled in some cases by irradiation of the thyroid. In signs of loss of ovarian function the changed basal metabolism became normal in most cases after irradiation of the thyroid and the symtoms decreased or disappeared completely. The results of roentgen irradiation were very encouraging in 12 cases of peritoneal tuberculosis; small doses of $\frac{1}{2}$ to $\frac{1}{4}$ skin unit dose were given. —*Andrey G. Morgan*

ACTION OF ROENTGEN RAYS AND RADIUM

ON THE

EYE AND EAR

EXPERIMENTAL DATA
AND
CLINICAL RADIOTHERAPY

BY

A. U. DESJARDINS

MAYO CLINIC

ROCHESTER, MINNESOTA

SECTION ONE

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(To be Continued in the November, 1931, issue)

(The Sections on the Action of Roentgen Rays and Radium on The Gastrointestinal Tract were published in the July, August and September issues, Volume XXVI, Numbers 1, 2 and 3.)

PREFACE

Strange as it may seem to the initiated, the existence of a scientific foundation for radiotherapy is even now being questioned. In a recent editorial in the Lancet* it was stated that "there is still an uncomfortable amount of truth in the gibe that the whole of radiology in its radiotherapeutic aspect lacks scientific basis and rests largely on an empirical footing." Casual reading of contemporary medical records bearing on the action of roentgen rays and radium often gives the impression that little is known concerning such action, in spite of the fact that, as far as many phases of the subject are concerned, more or less substantial or conclusive experimental data are available to indicate or to clearly establish the nature of such action. In some cases, indeed, the experimental indications are absolute. In other cases adequate experimental evidence may be lacking, but the clinical data may be sufficient to indicate the probable effect of irradiation. It must be admitted that many problems relating to radiotherapy are still the subject of controversy and that the large number of experiments which have been made have yielded only partial answers to many questions. Nevertheless, the experimental facts already established are sufficiently numerous to provide an adequate, although incomplete, scientific background. Unfortunately, the evidence furnished by experiments on animals and by clinical reports has never been brought together, analyzed, and correlated, and much of it has been lying on library shelves, buried in medical journals which are seldom read. Colwell and Russ and a few others have, it is true, examined some of this material and have made valuable deductions, but a thorough analysis and appraisal have never been undertaken.

Before the action of roentgen rays and radium on pathologic lesions can be understood it is essential to know the action of such rays on normal cells and tissues. The object of this work is to bring together the available experimental and clinical evidence and to subject this material to close scrutiny with a view to extracting from it the essential information about the effects of roentgen rays and radium on normal tissues and organs. The method adopted has been to prepare a careful and complete abstract of each original report, as published by the experimenters themselves, including every item of essential information therein contained. Every effort has been made to preserve as much as possible the meaning of the authors of such reports, even to the point of preserving ambiguous statements when such statements were present. These abstracts have been arranged in chronologic order to facilitate reference and enable the reader to follow the historical development of the subject. The experiments with roentgen rays have been grouped separately from those with radium. These two groups of experimental reports have then been subjected to critical analysis, and this follows the experimental reports themselves. The analysis, in turn, is followed by the clinical considerations, in which is taken up the therapeutic application of roentgen rays and radium to every disease by which the particular tissues or organs are affected. Finally, all the data, experimental and clinical, are correlated and summed up.

* Lancet, 1931, *1*, 141.

Although the greatest care has been taken to make this study as complete and as thorough as possible, I am conscious that errors, discrepancies, and oversights must have occurred. Certain experiments may unwittingly have been omitted. The opinions expressed are my own and for these I hold myself responsible. It is probable that, as time goes on and as fresh material becomes available, some of the deductions and conclusions may have to be modified. As far as the clinical considerations are concerned, it has been impossible to mention every report which has appeared in the literature, because this would have involved long lists of names which must serve only to tax the patience of the reader. In dealing with this phase of the subject, I have taken pains to include every author of importance and to give to each country due representation in proportion to the number of communications emanating from it. In this way, it will serve to indicate the country in which certain phases of radiotherapy have been most highly developed. The bibliography is substantially complete, although a few items which could not be procured have been omitted. I will appreciate having my attention drawn to any significant omission.

Rochester, Minnesota,
March, 1931.

ACTION OF ROENTGEN RAYS AND RADIUM ON THE EYE AND EAR

EYE

General Considerations

SOON after the discovery of the roentgen rays and their application to the diagnosis and treatment of certain conditions, a controversy arose over their visibility or invisibility. RÖNTGEN, in his original announcement, had rightly held that the rays were not visible. Later BRANDES (1897), RÖNTGEN (1897), DORN (1897), and many others who became interested in the problem, asserted that the rays gave rise to visual impressions, at least under certain conditions. This was based on the circumstance that, when persons with deficient vision or from whose eyes the lens had been removed were exposed to a roentgen tube under conditions excluding ordinary light, a vague sensation of light was, nevertheless, perceived. Further investigation, however, showed that the sensation of light sometimes caused by roentgen tubes was probably due to fluorescence of certain elements in the retina induced by the cathode rays, and that the roentgen rays themselves belong to the invisible portion of the spectrum, and, therefore, cannot produce any sensation of light.

GEISEL (1899), HIMSTEDT and NAGEL (1901), and JAVAL and CURIE (1902) called attention to the fact that, under certain conditions, radium also may give a sensation of light. In 1903, LONDON, of St. Petersburg, having verified this observation in blindfolded persons, and having established that the vague sensation of light induced by radium was due, not to the action of the rays on the optic nerve, but to the fluorescence of certain elements of the retina, attempted to take advantage of this effect to develop in the blind the ability to recognize certain objects and possibly to teach them to read. Attempts to use the direct effect of radium rays for this purpose were unsuccessful and potentially dangerous. London then conceived the idea of utilizing the indirect action of the rays, that is to say, the property of the rays of causing a barium platino-cyanide screen to fluoresce. His efforts were rewarded with slight success. An abstract of London's communication printed in the *Neuen Freien Presse*, of Vienna, under the title of "Hope for the blind," led Emperor William II, of Germany, to commission GREEFF (1904) to investigate and report on the subject. Greeff's studies led him to conclude that radium cannot give rise to a sensation of light in totally blind eyes, and that the vague perception of light by persons who are not totally blind is due to fluorescence of the retina, and therefore, to ordinary light, but not to a direct impression on the retina by radium.

Another closely related problem which at one time stirred scientific interest was the permeability of the lens to roentgen rays. Some observers at first contended that, although the other ocular structures were permeable to the rays, the lens, on the contrary, was relatively opaque. This early impression, which probably arose from the invisibility of the rays, was undoubtedly the result of the soft quality of the roentgen rays yielded by the apparatus then available. In other words, soft roentgen

rays possessing only slight penetrating power were absorbed by the more superficial elements of the eye. Later, however, when roentgen rays of shorter wave-length came into use, the relative opacity of the lens proved to be approximately the same as that of the other ocular structures. However interesting these problems may have been, they have little to do with the organic changes induced by irradiation in the various elements of the eye, and no further allusion to them will be made.

In many of the early investigations of the effect of roentgen or radium rays on the organism as a whole or on its different structures, the entire body of animals was exposed; in certain instances the eyes gave evidence that excessive irradiation under such conditions may cause irritation and inflammation of the eyelids and conjunctiva, and sometimes also of the cornea. Such ocular reaction, however, was seldom given the attention required to determine whether the clinical disturbances noted were a direct effect of irradiation or whether they were secondary to the action of the rays on other structures or to disturbances in the general metabolism. These early investigations contain so little of value with reference to the eye that they might well be disregarded, were it not for the fact that they gave rise to the legend that the eye is very intolerant of roentgen or radium rays and is easily injured by them. To this day the eye has generally been regarded as peculiarly sensitive to irradiation. It is but natural, therefore, that a large number of animal experiments should have been undertaken to determine the specific susceptibility of the eye and the relative sensitiveness of its different parts.

Animal Experiments

Roentgen Rays. CHALUPECKY (1897), struck by the apparent analogy between roentgen and ultraviolet rays in some of their effects on the eye, tested the action of roentgen rays on the lens and other elements of the eye. A small, red rabbit was placed in an iron box, from which only the head projected. The roengten tube[1] was placed beside the right half of the animal's face at a distance of from 6 to 10 cm. The action of the tube was first tested with a screen impregnated with barium platino-cyanide, in which the bones of the hand and the skull of the rabbit could be seen distinctly. Exposures of from forty-five minutes to two hours were then made daily or every second day. Slight contraction of the pupil and conjunctivitis and dermatitis over the right side of the face appeared on the ninth day after thirteen hours of irradiation; the pupil dilated only moderately after instillation of a 1 per cent solution of atropine. Fifteen days after the first exposure the conjunctivitis increased, flecks of secretion adhered to the cornea, the pupil contracted in spite of the atropine, and the eyelids became red, swollen, adherent, and hairless over an area of 0.5 cm. around the palpebral fissure. Elsewhere in this region the hairs were loose, could be extracted with ease, and the skin exuded. Because of the photophobia, eyelid retractors were used for the subsequent irradiations. During the next few days the loss of hair increased and the conjunctivitis continued. By the twenty-fourth day after the first session of irradiation, the alopecia extended over the entire right side of the face and was sharply circumscribed. The skin was covered with a thin crust, with slight underlying hemorrhage. The eyelids were markedly swollen and adherent; an abundant mucopurulent discharge bathed the chemotic conjunctiva; the cornea was slightly hazy and the pupil contracted, but the interior of the eye was normal. The conjunctivitis soon became purulent, the surface of the cornea was uneven and diffusely opaque, the appearance of the fundus was indistinct, and the alopecia extended over the right half of the head.

[1] The character of this tube was not described, but it was operated in connection with a Rhumkorff coil, which gave a spark of over 20 cm. The current was supplied by a battery of ten units, and the primary current varied between 12 and 16 amperes.

After the right eye and right side of the face had received eighteen sessions of irradiation, with a total duration of twenty-four hours, the cornea was completely opaque, the conjunctiva was covered with an adherent, fibrinous pseudomembrane, the palpebral fissure was smaller, and a symblepharon formed. The left eye and left side of the face remained normal. After further irradiation, the radiodermatitis and loss of hair extended over the skull and neck, and the crusts on the skin became thicker. The palpebral fissure became smaller and smaller and the cornea entirely grayish-white, but the general condition of the animal remained good. Chalupecky concluded that roentgen rays cause severe destructive changes, especially in the structures of the anterior segment of the eye (conjunctiva, cornea, iris).

Scholtz (1902) exposed the open eye of a rabbit ten times, each time for fifteen minutes, at a distance of 15 cm.[2] Complete necrosis of the skin around the eye occurred after four or five weeks, but aside from slight conjunctivitis, abnormalities of the eye or visual disturbance could not be demonstrated.

Baermann and Linser (1904) exposed the cornea of a rabbit to 8 Holzknecht units of roentgen rays,[3] but this did not give rise to any untoward symptoms.

Birch-Hirschfeld (1904) exposed one eye,[4] in each of five rabbits, to doses of from 10 to 20 Holzknecht units.[5] The animals were bound, protected from sparks and from "visible and invisible ultraviolet light," and their eyes were kept open with an eyelid retractor. The animals were killed after varying periods of clinical observation. The freshly enucleated eyes were opened in the equatorial plane, the lens placed in physiologic solution, and its permeability to roentgen rays tested. The anterior segment of the eyeball was fixed in Zenker's solution and imbedded in celloidin. The posterior segment was divided into three parts; the middle part, containing the medullary rays and optic nerve, was treated according to the method of Marchi, while the two other parts served as a source for specimens of the retina and choroid (methylene blue vital staining) and for the preparation of thin paraffin sections stained by the modified method of Nissl.

One albino rabbit received, in one eye, a dose of 20 Holzknecht units in thirty minutes at a "tube distance" of 10 cm., and the animal was killed thirty days later. The exposed eye remained normal for sixteen days, when conjunctivitis, at first slight but increasing for several days and accompanied by a mucopurulent secretion containing desquamated epithelium and an abundance of pus cells, developed. This was associated with contraction of the pupil, bleaching and hyperemia of the iris, and diffuse haziness of the cornea which, under the binocular loupe, appeared to be composed of fine points extending into the deepest layers of the cornea and resembled interstitial keratitis. Later the cilia of the upper lid fell out and ulcerations covered with scabs and with a slight tendency to bleed appeared at the margins and on the conjunctival surface of the lid. The conjunctivitis and keratitis continued until the death of the animal. The fundus remained apparently normal.

Microscopic examination showed marked thickening of the eyelid, with pronounced leucocytic infiltration beneath the epithelium and extending downward between the muscular fibers of the orbicularis; thinning of the epidermis, with deficient staining and vacuolization of the cells, and swelling of the outer layers of cells, the nucleus of which was distended or elongated and stained faintly with basic aniline dyes; irregular necrosis of the epithelium, with leucocytes and fibrin attached to the infiltrated bed; slight signs of atrophy in the muscle fibers where leucocytic infiltration had extended between the bundles; absence of hair follicles, and marked perivascular infiltration and endothelial degeneration of the ves-

[2] No other details given.

[3] The dosage factors were not given.

[4] The other eye of each animal was left unirradiated to serve as control.

[5] The roentgen rays were generated in medium soft tubes operated at a voltage equivalent to a spark-gap of 50 cm., in connection with a motor-driven interruptor making from 1300 to 1500 interruptions a minute. The intensity of the primary current was 2 or 3 amperes, and the "tube distance" 8 or 10 cm. The dose was measured by means of a Holzknecht chromoradiometer, and the reagent (probably pastilles of barium platino-cyanide) was fastened "close to the irradiated eye."

sels, with irregularity of the lumen resulting from vacuolization, loosening or proliferation of cells. The conjunctiva exhibited great, but irregular, degeneration and desquamation of the epithelium; marked leucocytic infiltration in the region of the limbus, especially around the hyperemic vessels; deficient staining of the nuclei; binucleated epithelial cells and atypical mitotic figures, with long, biscuit-shaped or dumb-bell-shaped nuclei, especially in the region of the conjunctival fold, and thickening of the vascular endothelium, with swelling and loosening of the cells. The changes in the anterior layers of the cornea consisted in necrosis and desquamation of the epithelium which, in places, was reduced to a single layer of cells with elongated nuclei; marked swelling of the epithelial cells, including the basal cells, around the periphery of the cornea; irregularity or duplication of nuclei and increase in mitotic figures, and dilated interstitial spaces, with leucocytes containing lobulated nuclei and distended or shrivelled corneal corpuscles in the substantia propria, especially near the periphery. Except for occasional foci of infiltration and newly formed blood vessels in the marginal areas, the deeper layers of the cornea were normal. The zone of degeneration was sharply delimited. Descemet's membrane was normal. The anterior chamber was filled with an "acidophile, crumbly mass" containing a few leucocytes attached as a fine precipitate to the posterior wall of the cornea. The iris showed hyperemia, slight thickening of the intima of some of the vessels, swelling of the epithelium of the ciliary body, and marked hyperemia of the processes. The lens was clear and the capsule normal. The vitreous also was normal. The changes in the retina were slight and many of the ganglion cells were unaffected, but other cells showed degenerative alterations, such as shrivelling, intense staining, and fine granular disintegration of the nuclear chromatin and vacuolization of the protoplasm. The choroid was hyperemic, but the walls of the vessels were normal, and there was no leucocytic infiltration. The optic nerve and the region of the medullary rays did not show evidence of degeneration.

A second, young,[6] gray rabbit with brown iris received, in one eye, a dose of 16 Holzknecht units of roentgen rays in fifteen minutes at a tube distance of 8 cm. Mucopurulent conjunctivitis appeared after a latent period of thirteen days, during which no evidence of reaction could be found with the binocular loupe or with the ophthalmoscope. The conjunctivitis increased for several days and was associated with keratitis and epilation of a portion of the lid. When the animal was killed on the thirty-ninth day after exposure the keratitis had diminished; the pupil reacted only slightly to atropine; the iris was faintly bleached, the lens clear, the papilla pale, and the vessels of the retina were narrow. Microscopic examination of the ocular structures disclosed changes of the same general character as, though less marked than, in the first rabbit, except in the retina and optic nerve. Birch-Hirschfeld thought the changes in the anterior segment of the eye either had not advanced so far or had already subsided to some extent. Nissl-stained or vital-stained (methylene blue) sections of the retina showed marked shrivelling of the ganglion cells, with enlargement of the pericellular space, disappearance of chromatin granules, and irregular shrivelling of the nuclei; loosening of the nerve fiber and inner plexiform layers; reduction in size of the inner granules, which were round, rich in chromatin, and stained homogeneously with thionin; round outer granules staining a homogeneous dark blue; scant signs of transverse ligaments, and granular disintegration of the outer segment of rods and cones. The pigment epithelium was normal, and the choroid hyperemic. The optic nerve (Marchi method) showed uniform myelin degeneration, intermingling of disintegrated and normal fibers, absence of interstitial leucocytic infiltration, thickening of the septums, but no particular increase in connective tissue and glial nuclei.

A third, adult rabbit with strongly pigmented iris received, in one eye, 10 to 12 Holzknecht units in twelve minutes, at a tube distance of 10 cm. The exposed eye and the adjacent tis-

[6] Age not stated.

sues remained normal for forty-one days, when slight haziness of the cornea appeared but subsided almost completely during the next two weeks. The fundus remained clinically normal throughout. The animal was killed fifty-nine days after irradiation. Microscopic examination showed only slight changes in the epithelium of the cornea, such as swelling of cells, marked formation of interfibrillar spaces in the anterior layers of the cornea, partial shrivelling of the corneal cells, and detachment and partial destruction of the stroma pigment. The posterior pigment layer of the iris also was partly destroyed, but the retina, optic nerve and choroid were normal.

A fourth, adult, black rabbit with strongly pigmented iris received, in one eye, 16 Holzknecht units in twenty minutes, at a tube distance of 10 cm. Moderate conjunctivitis and fine clouding of the cornea supervened after fourteen days; the conjunctivitis subsided gradually, but the corneal opacity continued until the animal was killed forty-one days after irradiation. The eyelids remained normal. Four weeks after exposure, ophthalmoscopic examination showed bleaching of the papilla and slight fading of the medullary rays. The pathologic changes, on miscroscopic examination of the irradiated eye after the death of the rabbit, were intermediate in degree between those observed in the first and second rabbits. The inflammatory reaction in the anterior segment of the eye was relatively slight or had completely subsided, while the degeneration of the ganglion cells of the retina was so pronounced as to lead to partial, but marked, atrophy of the optic nerve.

A fifth, young,[7] white rabbit received, in one eye, 12 Holzknecht units in twenty-five minutes, at a tube distance of 10 cm. Marked conjunctivitis and keratitis, loss of cilia and hair from both lids, and hyperemia of the iris appeared fifteen days after exposure, increased for several days, and gradually subsided. The lens remained clear, and no changes in the fundus were noted until four weeks after irradiation, when the papilla appeared gray, the medullary wings slightly faded, and the retinal vessels indistinct. The animal was killed forty days after exposure. The pathologic changes in the irradiated eye corresponded to those found in the first rabbit, but, either because they had never attained the same degree or had regressed further, the changes were less pronounced.

Birch-Hirschfeld pointed out that the inflammatory changes in the anterior segment of the eyeball were independent of the degenerative alterations in the posterior segment, and explained the variability in the degree of these changes in the two segments in these five rabbits as due to a difference in the penetrating power of the rays; that is to say, that rays which caused great superficial reaction had little effect on the deep structures, and vice versa. He also mentioned individual variation as a possible factor. The degenerative and later proliferative changes in the epithelium of the lids, conjunctiva, and cornea with swelling and vacuolization of the cells, and swelling, shrivelling or disintegration of the nuclei; the swelling, loosening or disintegration of the pigment epithelium and of the stroma pigment cells of the iris and ciliary body, and the alterations in the retina and optic nerve were attributed to the direct action of the rays. Birch-Hirschfeld admitted the difficulty of determining disturbances of vision in the rabbit, but thought the degeneration of the optic nerve shown by Marchi preparations proved a functional disturbance. He believed that roentgen rays affected primarily the nerve cells of the retina and not the fibers of the optic nerve. The changes in the ganglion cells were characterized by vacuolization of the protoplasm, shrivelling of the nucleus with disintegration of the chromatin, and dissolution of the cell membrane, but such changes were far from uniform.

To determine if the foregoing pathologic disturbances resulted from the direct action of the rays or if they might not represent an indirect effect of primary changes in the blood vessels, one atropinized eye in each of two rabbits, with the lids held apart by a retractor, was irradiated through a hole 3 mm. in diameter in a thick sheet of lead placed so that the

[7] Age not stated.

lead would protect the eye except for the center of the vascular cornea, which coincided with the small hole in the sheet of lead. The cornea of one rabbit was given 24 Holzknecht units and that of the other animal 8 Holzknecht units of medium soft roentgen radiation. Nine days after exposure the cornea of the rabbit which had received 24 Holzknecht units showed a central area of dullness, slight unevenness corresponding to the irradiated area, and small vesicular elevations of the epithelium. There was no pericorneal injection, and the conjunctiva was normal. Sections of the irradiated cornea, imbedded in celloidin and paraffin, showed normal epithelium in the peripheral zone; in the central, exposed area, irregular extension of the epithelial layer due to swelling of a portion of the cells, especially those of the middle layer; advanced vacuolar degeneration of some of these cells, with shrivelling and disintegration of nuclei; many binucleated cells, especially in the basal layer; an abundance of mitotic figures; absence of leucocytic infiltration, and dilatation of the interfibrillar space containing irregular corneal corpuscles. The changes in the irradiated central portion of the cornea of the other rabbit, which had received only 8 Holzknecht units, were similar but much less pronounced. Birch-Hirschfeld, therefore, concluded that, although disturbances in the blood vessels due to irradiation may play some part in the later phases, the changes in the corneal epithelium described by him must be attributed to direct action of roentgen rays.

Tribondeau and Récamier (1905), desiring to ascertain if roentgen rays influence the development of the retina, irradiated the face of a kitten[8] three days after birth for sixty minutes, in six sessions of ten minutes at the rate of three sessions a week. The beam of rays was focused on the right anterolateral half of the face, but the left eye also received a certain amount of radiation. Another kitten of the same age was used as a control. The palpebral fissures of the irradiated kitten opened two days sooner than those of the control kitten. Then for several days the eyelids were crusted and agglutinated; conjunctivitis and dullness of the cornea developed; large, whitish tufts appeared in the lens and vitreous humor of both eyes, coincident with progressive loss of vision; the eyes of the irradiated kitten, especially the right eye, remained smaller than those of the control animal. At necropsy, one month after the last session of irradiation, both eyes showed white tufts and diminished weight of the eyeball (right, 0.43 gm.; left 1.34 gm.). Microscopic examination of both eyes of the irradiated animal disclosed almost complete granular and vacuolar degeneration of the lens; marked fibrillary structure of the vitreous humor; normal development of the layer of rods and cones; atrophy of the internal granular layer; intense proliferation of the external granular layer in the form of folds and tubes dipping into the internal granular layer, especially toward the ciliary zone, and thickening of the layer of nerve fibers, but normal appearance of the optic nerve itself.

The skin of the irradiated portions of the face was inflamed and the hair fell at first; later the face had a flattened aspect and the skin remained abnormally thick. At necropsy, the head, stripped of its flesh by boiling, showed obvious asymmetry. The zygomatic arch and the superior maxilla were smaller, and the bony wall was thinner on the right than on the left side. The right orbit also was smaller than the left. The median sutures of the skull and face deviated, and the snout itself was twisted toward the right side, because of the greater development of the bones on the left side. Even the teeth were much shorter on the right than on the left side. Tribondeau and Récamier concluded that irradiation had retarded the development of the eye, had provoked structural anomalies in the retina and cataract formation with blindness, but had not affected the growth of the layer of rods and cones. The rays also had delayed the growth of the facial bones and teeth.

Von Hippel (1905–1906) irradiated a pregnant rabbit three times at intervals of two and

[8] The head of the animal was passed through a perforated sheet of lead protecting the body of the animal, which was wrapped in a towel and held by an assistant. The focal-skin distance was 10 cm., but the other technical conditions were not mentioned.

three days, respectively, and eighteen days after the third exposure two young were born and lived one hour. One of these had a left palpebral fissure 8 mm. long with normal closure of the temporal half, but with a wide, oval opening of the nasal half; the opening of the lids on the right side was still greater, and the upper lid was distinctly curved. Focal illumination showed, in the lens of each eye, a very small, gray, central dot, which persisted on transillumination. The other young had normally adherent palpebral fissures, but the lens exhibited a delicate, annular cloud, which may have been only a nuclear reflex. The next day, nineteen days after the third exposure of the mother, two full-term, but cadaverous, young were stillborn. In one the nasal portion of both palpebral fissures gaped, and the lids, especially the upper lids, were too short. The enucleated eyes showed a central cataract. In the other young, the lids were almost completely lacking from the right eye; the lids of the left eye were normally adherent. Two days later, twenty-one days after the third irradiation of the mother, two more cadaverous young were stillborn, and the mother was found dead beside them. The eyelids were largely lacking. In one fetus the placenta was adherent and amniotic bands passed toward the trunk, against which both anterior extremities were pressed. Microscopic anomalies were not found in the eyelids, which merely appeared too short; in one of the young the amnion was firmly attached to the margin of the lid. Von Hippel assumed that early adhesion of the amnion to the lid prevented the lids from fusing normally and caused the defects noted.

Another pregnant rabbit was irradiated three times at intervals of two days and died seventeen days later. The abdominal cavity contained bloody, serous fluid; the uterus was studded with hemorrhages and contained four macerated fetuses of different sizes. In each of these the nasal portion of the palpebral fissures gaped slightly. Von Hippel regarded these defects in the eyelids, the cataract in one of the young of the first rabbit, and the death of most of the fetuses as results of irradiation. In three of the animals hemorrhages in the anterior and posterior chambers were found only in one eye. Microphthalmus with coloboma was found in one eye of each of the two newborn rabbits, but the relation of this observation to irradiation was uncertain.

Belley (1907) studied the effect of roentgen rays on the rapidly developing eyes of ten newborn kittens. These animals were selected because the retina of the cat does not attain its full development until some time after birth. He irradiated one eye of each kitten, the other eye being left unexposed to serve as control. The animals were first wrapped with a napkin, and then rolled in a sheet of lead up to the head to prevent all movements. The head was then covered by a separate sheet of lead with a perforation corresponding to the eye chosen for exposure. Three series of kittens were exposed to roentgen rays of three somewhat different qualities. One eye of each of four kittens less than three days old was irradiated[9] with very soft roentgen rays.[10] The eye of one animal was exposed for fifteen minutes twenty hours after birth and for a second session of fifteen minutes two days later. The second kitten, three days old, and the third and fourth kittens, each two days old, were irradiated[11] for forty-five minutes in three sessions, each of fifteen minutes' duration, at intervals of two days. Two other kittens two days old were exposed to roentgen rays of slightly shorter wave length.[12] The eye of one animal was irradiated for half an hour in three sessions of ten minutes each, with an interval of two days between sessions. The eye of the second animal

[9] D'Arsonval-Gaiffe industrial transformer operating with Villard valve tubes on 45-cycle alternating current. The roentgen rays were generated by a Chabaud-Villard tube, either with an ordinary anticathode or with a cooled anticathode. The primary voltage varied between 50 and 55 volts at 3 amperes; the milliamperemeter in the secondary circuit oscillated between 0.5 and 1.2 milliampere; the secondary voltage, measured with a Bergonié electrostatic voltmeter, was not stated, or rather was given as the quality of rays according to the Benoist radiochromometric scale; the focal-skin distance was 10 cm.

[10] Rays corresponding to from No. 2 to No. 4 on the Benoist scale. Intensity of current, 0.5 ma.

[11] Intensity of current 1.0 to 1.5 ma.

[12] The quality of the rays, as measured with a Benoist radiochromometer, given as about 4 to 5. These would now be regarded as "soft" rays, but not so soft as the rays equivalent to from 2 to 3 on the Benoist scale used in the first series of experiments.

was exposed for one hour in five sessions of twelve minutes each at intervals of two days. One eye of each of three other kittens, from twenty hours to five days old, was exposed to roentgen rays of medium quality.[13] One animal was irradiated[14] for five minutes in one session; one for fifteen minutes, also in one session, and one for thirty minutes in two sessions of fifteen minutes each, with an interval of three days. The animals were killed with chloroform after varying periods of observation. The eyes were immediately extirpated, fixed in 10 per cent formalin or in Telliesnicky's acetic bichromate solution, measured and weighed, imbedded in paraffin, and sections were stained with hemalum-eosin, hematoxylin-ferric eosin, and hemalum-safranin (Rabl-Regaud).

The first effect noted in some of the animals of each of the three series was that the opening of the lids in the exposed eye occurred a few hours sooner than in the unirradiated eye. This was interpreted as due to increased destruction of the epithelial cells which still united the lids. Later the palpebral slit of the exposed eye remained smaller than that of the other eye, and this difference increased with the period of observation, and varied in degree with the dose of radiation. Radiodermatitis of the skin of the lids occurred in the exposed eye of all but one of the kittens which had been irradiated for only five minutes with roentgen rays of medium quality. The lids became red and swollen, the hair fell, and the skin remained smooth and atrophic. When the animal was allowed to live long enough, the hair always grew again, but such growth was slow and the hairs were small, white, and far apart. Pigment in such regenerated hairs reappeared only after a long interval. The microscopic appearance of the lids depended on the time elapsed after irradiation. Epithelial degeneration, hyperemia, and leucocytic infiltration were the early features; disappearance and subsequent reappearance of the hair follicles were later changes, and these coincided with connective tissue sclerosis of the lids.

The conjunctiva was more sensitive than the skin of the lids, and the conjunctivitis developed before the dermatitis. Mucopurulent inflammation with rapid agglutination of the lids by dried discharge, was a constant observation; the conjunctivitis continued in a subacute form for some time, but subsided slowly and finally disappeared. Early hyperemia and intense polymorphonuclear leucocytic infiltration of the conjunctival epithelium and of the underlying chorion characterized the acute stage. The acute phase of conjunctivitis was accompanied by haziness of the cornea, lasting only a few days, the chief features of which were irregularity and increased staining of nuclei and slight polymorphonuclear leucocytic infiltration. The irregular thickness of the anterior and basal layers of epithelial cells, the wavy appearance of the corneal margins, the abnormal aspect of the nuclei, and the leucocytic infiltration of the anterior epithelium, which sometimes extended into the substantia propria around the limbus, persisted to a slight degree after the cornea had apparently returned to its normal condition.

In one animal of the last series, after exposure for thirty minutes to roentgen rays of moderate wave length, flakes of albuminous precipitate were noted in the aqueous humor. In all other animals the anterior chamber was normal by the time the subsiding keratitis allowed the eye to be examined. The only alteration noted in the iris was retardation in the formation of pigment; the normal changes in the color of the iris took place much more slowly in the irradiated than in the unexposed eye. Pathologic alterations were not found in the choroid. The vitreous body was abnormal in only one instance; the abnormality consisted in cloudiness of the vitreous and blurring of the papilla. The fibrillar structure of the vitreous was more marked than normal. Thickening of the hyaloid membrane also was noted in one animal.

Degeneration of, and cataract formation in, the crystalline lens were found in all but one of the animals, even in those killed between fifteen and twenty-three days after irradiation.

[13] Corresponding to 6 or 7 of the Benoist radiochromometric scale.

[14] Intensity of current, from 0.3 to 0.6 ma.

This cataractous degeneration started around the periphery and gradually extended toward the center of the lens; it was not perceptible clinically until about thirty-three days after exposure to roentgen rays, but could be detected microscopically much earlier as a zone of small vesicles around the marginal portion of the lens. Later the entire lens became uniformly milky. This process was accompanied by increasing atrophy of the lens and vitreous body and by adhesive drawing backward of the iris. The cataract apparently started in the lenticular epithelium by flattening of the cells and nuclei, by destruction and disappearance of some of these cells, and later by hyperplastic thickening of the anterior layer of epithelium, changes which were most marked in the equatorial zone.

Degenerative or inflammatory changes were not observed in the retina of any of the animals. The only abnormality consisted in a curious malformation characterized by multiple folds of the anterior half or two-thirds of the external granular layer and the layer of rods and cones, giving to these layers a plicated appearance, as if these normally developing layers had been made to assume a sinuous form by failure or retardation of development of the coats external and internal to them. This was slight in the irradiated eye of some of the animals and marked in others; in some it was so marked as to cause the arrangement of these coats to resemble the acinous formation of the gastric glands. Buds of external granular cells were sometimes isolated at the bottom of some of the folds and resembled exactly the "rosettes" described by Wintersteiner as pathognomonic of glioma of the retina. This formation, which was always most pronounced in the region just behind the ora serrata where the full thickness of the retina begins, and which extended backward and generally occupied more than half of the membrane, was observed in seven of the nine animals, and its degree corresponded roughly with the duration and intensity of irradiation and with the subsequent period of observation. The two animals which did not show this change had been killed too soon after exposure.

In all but one of the animals the irradiated eyeball was smaller than that of the unexposed eye. The degree of this developmental retardation varied with the duration and intensity of irradiation, but still more with the time elapsed between irradiation and death. The single animal which did not show such retardation was killed eight days after irradiation, and this interval was not sufficient to show any appreciable difference in size between the two eyes. In most of the kittens, this difference was perceptible during life. The development of the exposed eye did not stop entirely, but was much slower than normal and the retardation continued at the same rate during the period of observation. Moreover, in one animal observed for five months after exposure, the cataract formation and the consequent atrophic changes caused a still greater difference in the size and weight of the two eyes.

Tribondeau and Belley (1907) irradiated[15] one eye of each of ten newborn kittens, the remainder of the head and body of the animals being shielded with lead. The first exposure was always made between one and five days after birth, and the dose was such as to avoid radiodermatitis. Soft roentgen rays of long wave length caused inflammation of the lids and cornea, but had little effect on the crystalline lens. Medium or hard rays (medium or short wave length), on the contrary, caused the lens to degenerate. The rapidity and degree of cataract formation was proportional to the dose of radiation, but only small doses were necessary to produce it. The cataract began at the periphery or equator of the lens and, with mydriasis, appeared as an annular, cloudy zone composed of a multitude of small, confluent vesicles. Later, whitish tufts appeared in the pupillary field and gradually invaded the entire lens, which became opaque. The iris preserved its reflex reaction to light. Atrophy of the lens and increase in depth of the anterior chamber became evident some time afterward.

Microscopic examination of sections of the irradiated lenses showed that the epithelium on the anterior surface of the lens was affected first. At this stage the crystalline fibers and

[15] d'Arsonval-Gaiffe apparatus; focal-skin distance, 10 cm.; duration of exposure up to ten minutes every three days. The quality of the rays, the total duration of exposure, and the subsequent period of observation were intentionally varied.

capsule were normal. The epithelial layer disclosed more or less extensive breaks, and these cellular gaps were especially frequent in the retro-iridian zone of the anterior surface. The nuclei of the neighboring intact cells often showed alterations in shape and staining quality. Changes in the crystalline fibers themselves soon occurred in the equatorial region of the lens; these fibers became swollen and varicose, and their normal, finely serrated margins then appeared as sinuous lines. Discrete vacuoles gradually became confluent and formed wide, granular plaques. These changes spread rapidly throughout the lens, and only a few groups of recognizable fibers remained. Later still, the anterior face of the lens showed patches of epithelial desquamation, separated by areas of cellular proliferation, sometimes forming nodules 80 μ thick. The capsule of the lens remained unaffected for a long time, but finally thickened, and its anterior portion sometimes became double its normal thickness by virtue of connective tissue lamellae arranged much as in the substantia propria of the cornea. The lenticular atrophy was unmistakable in median sections of the eye, and five months after irradiation the lens was sometimes only half normal size. Tribondeau and Belley concluded that the cataract formation observed was a direct effect of roentgen rays on the developing epithelium of the lens.

Tribondeau and Belley (1907), in the course of their experimental production, with roentgen rays, of cataract in the eyes of newborn kittens, also found that irradiation caused microphthalmia. Slight microphthalmia was obtained with difficulty with soft roentgen rays[16] in two kittens exposed for forty-five minutes at the age of sixteen and twenty-three days, respectively. The irradiated eye of one animal did not change, whereas that of the second animal showed only a slight difference in weight. The microphthalmia occurring after exposure to moderate or hard rays[17] was definite and constant, but became evident only after a rather long period of observation allowing sufficient time for the unexposed eye to grow; retardation of development in the irradiated eye caused it to remain small. Very small doses of such rays were sufficient to bring about microphthalmia, which was still greater after larger doses. The weight of the irradiated eye was only one-third or one-half that of the normal, unexposed eye. Considerable variation in individual susceptibility was noted. Tribondeau and Belley attributed the microphthalmia to retardation of development. To ascertain whether or not the irradiated eye would recover its normal rate of growth one of the animals was kept under observation for five months. The exposed eye remained smaller than the unexposed organ; the former, indeed, diminished in size during the late portion of this period, and this was regarded as due to the cataract and to the lesions in the retina.

Tribondeau and Belley also observed, in nearly all cases, a retinal lesion consisting of a series of folds in the outer layers of the anterior half of the membrane, especially around the ora serrata. Jacob's membrane dipped toward the interior of the eye and formed tubules covered by the granular coats, especially the external. These tubules, in places, became pedunculated or even appeared detached and resembled Wintersteiner rosettes. This analogy gave an impression of early glioma, but prolonged observation failed to show any neoplastic growth. These folds in the anterior portion of the retina were regarded as due to the microphthalmia itself, and the authors reported having seen a similar formation in a microphthalmic child. They concluded that the development of the outer coats of the eye was probably affected by the rays to a greater degree and more rapidly than the retina, the anterior portion of which continued to grow and to arrange itself in folds.

Von Hippel (1907) tried to determine the effect of roentgen rays on the eye of rabbit embryos by irradiating the abdomen of pregnant rabbits, by exposing the body of pregnant rabbits with the abdomen excluded by thick sheets of lead, and by injecting cholin subcutaneously into other pregnant rabbits without exposure to roentgen rays. His object was to ascertain if any effect produced on the ocular structures was due to direct action of the

[16] 3 to 4 (probably refers to the Benoist scale).
[17] 5 to 8 (probably refers to the Benoist scale).

rays or to toxic substances generated in the body by irradiation or by subcutaneous injections of cholin. An attempt was made to exclude hereditary factors as much as possible.

The first series consisted of twenty-one experiments, in each of which the abdomen of a pregnant female was irradiated[18] two or three times on successive days or at intervals of from one to three days, and from six to eleven days after exposure to impregnation. Three of the rabbits failed to become pregnant; two died five and seventeen days, respectively, after the last session of irradiation, and neither was pregnant. Two others died on the day of the third irradiation, and only small amniotic sacs were found in one of them; the other was not pregnant. All the remaining females conceived and brought forth from one to ten young, many of which were born dead, whereas those born alive died during the next few days; only one lived longer than two weeks. Unfortunately, careful necropsy on the young was made only in connection with the last experiments of this series. Extensive hemorrhage in the mucosa and serosa of the stomach and intestine was found in one litter. The embryos of two litters were obtained only at necropsy and were excluded for this reason. Seven of the twelve remaining litters contained individuals with opacity of the crystalline lens (cataract). In one of the litters three of five embryos showed bilateral lenticular opacification; in a second, one of two; in a third, one of six; in a fourth, six of eight; in a fifth, all of three; in a sixth, three of six, and in a seventh, the single embryo had cataract in both eyes. Therefore, eighteen of thirty-one embryos from seven litters had bilateral cataract. The twenty-six embryos from the five other litters had normal lenses.[19] In one litter of six embryos, bilateral coloboma of the lids was noted in four of the embryos, and unilateral coloboma in one. Microphthalmia of one eye also was noted in one of the embryos of the same litter. The opacity of the lens was central and varied in size, lamellar and almost always incomplete, especially when circular, or annular and situated in the anterior corticalis, directly beneath the capsule.

The animals were generally killed by decapitation and the eyes were removed immediately afterward. The lenses were fixed in Müller's formol or Zenker's solution as modified by Birch-Hirschfeld, and meridional and equatorial sections from 7 to 10 μ thick were made. The staining methods were not described, but some unstained sections, kept in water or glycerin, also were examined. Von Hippel stated that the evaluation of the pathologic changes in the lenses of newborn rabbits was difficult by reason of possible post-mortem changes and of artefacts due to methods of fixation. In the center of the lens of some of the embryos there was an egg-shaped zone of total degeneration, with amorphous, granular masses interspersed with clumps of nuclear residue. The fibers around the border of this zone were swollen and merged so gradually into the normal as to give to this zone an ill-defined appearance. In one instance, besides the central zone of lenticular degeneration, a layer of coagulated fluid separated the posterior capsule from the substance of the lens. In other instances the cataractous change extended to the anterior capsule and was characterized by swelling and disintegration of the fibers, between which fluid and free nuclei were scattered. In the lenses of the embryos with lamellar cataract generally there were swelling and irregularity of the fibers, central degeneration, nuclear rests deposited in clotted fluid, and masses of thickly crowded vacuoles in a circular zone between the outer limits of the transitional fibers and the nuclear zone. These vacuoles did not always correspond to the macroscopic opacity, because in some cases an abundance of similar vacuoles was observed in the equatorial region where the lens appeared clear. In other cases spindle-shaped distention of the fibers was found in the perinuclear zone, especially in the deep layers of the lens, but similar distention was sometimes seen in clear lenses. Pathologic data such as those described were noted in about half of the lenses with lamellar cataract. The lenses of some of the embryos with annular opacity

[18] The only details given concerning the irradiation were that the rays were "medium soft" in quality and that 7 Holzknecht units were given at each session; this dose required an exposure of from fifteen to twenty minutes.

[19] It was impossible to verify accurately the figures in the tables which accompanied the original report.

exhibited widening and swelling of the lenticular fibers, which had a finely granular appearance; in other lenses the annular opacity seemed to be produced by dense collections of droplets in the anterior cortical layer. Conclusive evidence of abnormality was not found to account for opacity in the lenses of half of the animals.

The second series comprised seven experiments on six pregnant animals. The abdomen of each animal was covered with a plate of lead to protect this part of the body from the rays. Any effect on the embryos must, therefore, be indirect. The animals were irradiated in the same manner as those of the first series, from six to eighteen days after exposure to impregnation. Three failed to become pregnant. One of the other animals became pregnant twice after three exposures to roentgen rays. Of the thirty-one young from the four litters, twenty-seven were found with a normal lens in both eyes. One animal of the four litters had a delicate ring of opacity in the anterior cortical layer of the lens of the right eye and blood in the anterior chamber of the left eye. Two animals from another litter had defects in the lids, and these two and a third from a different litter had bilateral microphthalmus and coloboma. A definite pathologic basis for the annular opacity of the lens of one eye observed in one of the young in this series was not found.

The third series comprised eighteen experiments, but ten were excluded, because the animals did not become pregnant. Five of the eight remaining experiments were made on one animal, which, seven days after exposure to impregnation, received five daily injections of 5 c.c. of a 1 per cent solution of cholin. Later, eight well-developed young were born, but one was dead. Bred again one month afterward (cholin not injected), the animal gave birth to five young, all of which had cataract formation and two had hemorrhage into the anterior chamber of one or both eyes. The eight and four young, respectively, of two litters from different mothers did not have lenticular abnormalities. On the contrary, the four, five, and four animals, respectively, of three other litters all had bilateral cataract. Hemorrhage in the left eye was noted in two of the thirteen and in both eyes in two. One animal from another litter of two had bilateral cataract. The lenticular opacity in all the affected eyes was generally central and either lamellar or punctate in appearance. Annular opacity was noted in a few instances. The only microscopic changes which seemed to correspond to the opacity of the lens were widening of the lenticular fibers and an abundance of fine, refractile vacuoles. In some cases these vacuoles were rather large and closely packed. In other opaque lenses no such abnormalities were seen, although they were sometimes noted in lenses which appeared clear. In the lens of one of the animals in this series there was observed a peculiar spherical opacity, which disappeared in less than one minute and for which a pathologic basis was not found.

Von Hippel hesitatingly assumed that the presence of abundant vacuoles in the substance of the lens, with or without swelling of the fibers, and the presence of clumps of nuclear débris, were the pathologic representatives of the opacity noted in the lens of many of the young animals. He attributed the defects of the lid to amniotic adhesions, tended to regard the occurrence of coloboma and microphthalmia as results of coincidence, and concluded that the cataracts noted in the young of rabbits after abdominal irradiation, after irradiation of the body exclusive of the abdomen, and after injection of cholin solutions must have been due to an indirect and probably toxic effect of roentgen rays or of cholin. An attempt was not made to explain the mechanism involved.

Tribondeau and Lafargue (1907), impelled by the studies of Tribondeau and Belley, who had found that irradiation of the eye of young animals leads to the formation of cataract (see pages 9 and 10), undertook to investigate the action of roentgen rays on the fully developed eye of adult animals. With this object they irradiated[20] the eye of four adult rabbits for from five to sixty minutes. Two rabbits were exposed for five and fifteen minutes,

[20] Chabaud-Villard tube; focal-skin distance, 10 cm.; quality of rays, 5 to 7 (probably Benoist scale); no other technical details given.

respectively, at one session, and two other rabbits were exposed for thirty and sixty minutes, respectively, in several sessions of fifteen minutes each, at the rate of three sessions a week. The animals were killed one and a half months later. Ophthalmoscopic examination of the irradiated eyes during life and at necropsy, as well as histologic examination, failed to disclose the slightest abnormality in the crystalline lens. Tribondeau and Lafargue concluded that the fully developed lens of adult animals is resistant to roentgen rays; in other words, that the lenticular epithelium, which they had previously shown to be readily affected by irradiation during the developmental phase of early life, becomes very resistant after full development.

Tribondeau and Lafargue (1908) irradiated[21] the right eye of each of four rabbits one year old. The right eye of the first and second rabbits were exposed to roentgen rays for five and fifteen minutes, respectively, in one session, followed by a period of observation of two months. The right eye of the third and fourth rabbits was exposed for forty-five minutes and two hours, respectively, in several sessions of fifteen minutes each, and the animals were allowed to survive for one and a half months. The first rabbit showed nothing abnormal, except slight radiodermatitis of the lids. The third and fourth rabbits developed complete epilation in the irradiated territory and an intense kerato-conjunctivitis; the inflammation of the conjunctiva and cornea of the fourth animal was so severe that perforation of the cornea was feared, but complete healing occurred. At necropsy, the transparent mediums in all four irradiated eyes were clear, and the only inflammatory residue in the fourth rabbit consisted in thick, smooth and discolored lids. Sections of different portions of the irradiated and unirradiated eye of each animal were subjected to a meticulous microscopic examination. The sections were stained by the Van Gieson, Cajal, Marchi, and Rabl-Regaud methods.

Neither macroscopic examination nor microscopic mensuration of the sections furnished the slightest evidence of atrophy of the optic nerve. The sections stained by the Van Gieson and Cajal methods failed to disclose any sclerosis and demonstrated the integrity of the axis cylinders of the exposed nerve. Tribondeau and Lafargue considered the Marchi method, which Birch-Hirschfeld had used, unreliable; in spite of rigid technique they observed only once the precipitation of osmium on about one-tenth of the optic nerve. According to them, the retinal lesions described by Birch-Hirschfeld as results of roentgen irradiation were normal conditions or artefacts misinterpreted as pathologic changes. They stated that, if they had examined only the irradiated eye of each animal, their observations must have corroborated those of Birch-Hirschfeld. The retina of the irradiated eyes presented many aspects which might have been taken as pathologic had not the retina of the unexposed eye of the same animal appeared identical. Tribondeau and Lafargue attributed many of these apparent cellular alterations to the action of fixing agents. They were unable to find any pathologic changes in the retina due to irradiation. In spite of longer exposure of the eye to stronger doses of roentgen rays than those used by Birch-Hirschfeld, Tribondeau and Lafargue found that roentgen rays do not have any degenerative effect on the optic nerve or on the retina.

Tribondeau and Lafargue (1908) presented data on a cat, each of whose eyes had been exposed to roentgen rays[22] one and two months, respectively, after the opening of the eyelids. In one eye, irradiated for thirty minutes one month after the separation of the lids, cataract developed. The other eye, irradiated for one hour two months after the separation of the lids, remained unaffected. Tribondeau and Lafargue concluded that the radiosensitiveness of the lens diminishes rapidly, and that the lens soon acquires great resistance to the action of the rays.

Bossuet (1909) investigated the action of roentgen rays on the lens of fetal, newly born,

[21] Focal-eye distance, 10 cm.; current intensity, 0.5 ma.; quality of roentgen rays, 6 to 7 Benoist (relatively soft).

[22] Focal-skin distance, 10 cm.; current intensity, 0.5 ma.; the other technical conditions were not specified.

[23] Voltage equivalent to a spark-gap of 50 cm.; primary current, 10–12 amperes; medium soft Bauer tube; intensity of the rays not measured; tube distance, 10 cm.

and adult guinea pigs, rabbits and dogs. Two pregnant guinea pigs were irradiated[23] over the abdomen[24] for fifteen and twenty minutes, respectively, three times at intervals of two or three days. About fourteen days after the irradiation of an animal for forty-five minutes slight radiodermatitis of the abdomen developed, and the next day the animal gave birth to two dead but fresh fetuses. The eyes were immediately enucleated and examined with a Zeiss binocular microscope. There was clouding of the lens in the region of the pupil, but this was not sufficient to be regarded as pathologic. Microscopic examination of the lenses disclosed a peripheral zone of lenticular degeneration extending deeply into the cortex and consisting of Morgagni globules, spindle-shaped swelling of the fibers, and fine granular masses; these changes were more pronounced in the anterior than in the posterior corticalis. The nucleus, the transitional zone, and the equatorial parts outside the ring of degeneration were normal.

Eleven days after the third exposure to roentgen rays, the other pregnant guinea pig gave birth to four young; one was greatly macerated, one had been dead for several hours, and the two others died during the second day. Six eyes were fit for study; four were opened and the posterior surface of the lens was examined at once with the binocular microscope, but pathologic changes were not found. Microscopic examination of sections[25] of the lens of the six eyes revealed deficient staining and degeneration of the capsular epithelium, and destruction of the anterior portion of the corticalis, in the equatorial part of which was swelling of the fibers and a meshwork of vacuoles. Only slight changes were noted in the posterior portion of the corticalis; the nuclear and transitional zones were normal.

The anterior portion of a young dog four days old and of a black rabbit two weeks old was exposed to roentgen rays for thirty and twenty-five minutes, respectively, at a tube distance of 10 cm., and without any protection. The dog died nine days after exposure. In the lenses were proliferation and marked degeneration of the capsular epithelium. The nuclei were irregular in form and stained irregularly. The anteroposterior section had somewhat the appearance of a lamellar cataract, with a broad ring of degeneration involving all sides of the lenticular nucleus and consisting of vacuoles and swollen fibers. The destruction was greatest at the equator and on the posterior corticalis and least in the central portion and anterior corticalis. The nucleus, transitional zone, and external cortical layer were intact. Twelve days after irradiation, loss of hair, edematous swelling of the skin, and marked injection of the conjunctival vessels were noted. The conjunctivitis soon became purulent, the skin of the face became loose, and the hair fell from the thorax, forefeet and neck. Distinct clouding of both lenses became perceptible five weeks after irradiation, and after seven weeks a complete cataract had formed, with a shallow anterior chamber and narrowing of the palpebral fissure. The conjunctivitis continued and the hair grew again in the depilated areas, but the new hair was white. All parts of the body which had been irradiated were delayed in growth; the head, one side of the thorax and the forefeet were considerably smaller than the corresponding parts of a control animal. The irradiated half of the skull of both animals differed considerably in size, and the brain weighed 7.5 gm. in contrast to 9.0 gm. for that of the control animal. The eyes of the irradiated rabbit had a volume of 1.5 c.c. and 2 c.c., whereas those of the control rabbit had a volume of 3 c.c. Microscopic examination of sections of the lenses disclosed complete degeneration of some of the capsular epithelial cells with disintegration of the nuclei and vacuolization of the protoplasm; proliferation of other epithelial cells with inward cone-like projections into the anterior corticalis; broad layers of pseudo-epithelium and large cyst-like structures, partly free and partly covered with pseudo-epithelium, in the posterior corticalis. Iritis with posterior synechia and exudate in the anterior chamber, cyclitis with degeneration of the pigment epithelium, "pronounced changes in the retina," papillitis and optic neuritis also were present.

[24] The remainder of the body was protected with lead plates or staniol.
[25] The methods of fixing, imbedding, and staining were not mentioned.

Two dogs four days old and two dogs six days old were irradiated as follows: the right eye and right half of the face of one animal for twenty minutes at a tube distance of 3 cm.; the right eye and surrounding tissues of another animal for fifteen minutes at a tube distance of 5 cm.; the right eye only of the two remaining dogs for three and eight minutes and at a tube distance of 5 cm. and 3 cm., respectively. Ten days later the first animal manifested pronounced radiodermatitis, with loss of hair and, later, deep ulceration of the skin. The dermatitis healed in five weeks, the hair grew back in the exposed region, and the palpebral fissure became very narrow, but without loss of palpebral function. Slight haziness of the cornea in the form of a precipitate on its posterior surface, marked opacity of the lens, and marked decrease in size of the irradiated right half of the face were observed after seven weeks. The volume of the unexposed normal eye was 3.5 c.c.; of the irradiated eye, 1.5 c.c. In the macerated skull, the right orbit and right half of the face were very small and the teeth were ill-formed. Microscopic examination of sections of the irradiated lenses disclosed pronounced degeneration and irregular destruction of the capsular epithelium, with vacuolization of the protoplasm; peripheral degeneration of the lens, especially marked on the posterior surface, where the defect was partly covered by broad layers of pseudo-epithelium; vacuolization, Morgagni globules and fine granular masses in the posterior capsule; thick clumps of proliferated and degenerating epithelium in the anterior corticalis, and extensive destruction of fibers in the central portion of the corticalis. Iritis, with a cellular, fibrinous exudate, loosening of the posterior pigment epithelium, with adhesions to the lenticular capsule, and loosening of the retina also were noted. In the second dog, killed one month after irradiation, substantially the same changes were found. Twelve days after irradiation of the third and fourth dogs, transient conjunctivitis developed, with only slight epilation and contraction of the palpebral fissure; the fourth animal had a transient edematous swelling in the exposed area. They were killed thirty-three and thirty-four days, respectively, after exposure. The volume of the exposed eye of the third dog was 1.8 c.c., and of the normal eye, 2 c.c.; the volume of the exposed eye of the fourth dog was 1.6 c.c., and of the normal eye, 2 c.c. Microscopic inspection of sections of the irradiated lenses disclosed changes similar to, although less marked than, those noted in the preceding animals. This was especially true of the third animal, whose right eye had been exposed for only three minutes. The nucleus of the lens was normal.

The third series of experiments consisted in irradiating both eyes of two adult rabbits for forty-five minutes and of two adult guinea pigs, one for forty-five and one for ninety minutes, at a tube distance of 5 cm. The rabbits were killed two and thirty-one days, and the guinea pigs ten and eleven days, respectively, after the single exposure to roentgen rays. The fresh lenses were placed in 50 per cent alcohol for a short time, then in absolute alcohol, and finally in distilled water. The capsule, now raised like a vesicle, was removed with forceps and stained by the "usual methods." Nothing clinically or histologically abnormal was found in the eyes of the rabbit killed two days after exposure. In the rabbit killed thirty-one days after exposure slight conjunctivitis, degeneration of the capsular epithelium of the lens, globular degeneration of the nuclei, and vacuolization of the cellular protoplasm in the equatorial region of the capsule were observed. Blepharitis and keratitis occurred in one guinea pig and conjunctivitis in the other. The microscopic appearance of the lenses of these two animals was the same as in the rabbit killed thirty-one days after irradiation, but the changes were less marked.

Bossuet concluded that roentgen rays may injure the mature as well as the growing lens of young animals, but that the effect is much greater in the latter than in the former. He explained the greater destruction in the equatorial and posterior cortical regions by the presence in these regions of the youngest and most rapidly growing cells, and the cellular proliferation in the lenticular epithelium as a compensatory attempt at regeneration or as a direct stimulating effect on the cells.

Rollet and Malot (1914) investigated the action of roentgen rays on the eye of three normal rabbits,[26] after a preliminary ophthalmoscopic examination by Aurand to establish the normal condition of the eyes. The left eye of two rabbits was then irradiated[27] for fifteen minutes on four separate occasions at intervals of two or three days. Ocular abnormality was not found ophthalmoscopically two days after the last irradiation. One rabbit died three weeks later, but the cause of death could not be determined. Fifty-eight days after the last irradiation, the left eye of the other rabbit was again exposed to roentgen rays for fifteen minutes on each of five occasions, at intervals of two or three days, under the same technical conditions. Changes were not found in the exposed eye five days after the last irradiation. A third series of six fifteen-minute exposures was given to the same eye under similar conditions, except that the rays were unfiltered. Nineteen days after the last exposure, marginal epilation of the eyelashes and purulent conjunctivitis developed. Slight blepharitis was still present fourteen days later, but the cornea and the fundus of the eye were normal.

The left eye of a third rabbit, with normal ocular fundus, was exposed to roentgen rays[28] once for fifteen minutes, but no change was perceptible in this eye six days later. After a lapse of fifty-six days, the same eye was irradiated[29] five times at intervals of two or three days. The lids and eyeball were normal five days after the last irradiation, and two days later (seven days after the last previous exposure) six additional sessions of irradiation, each lasting fifteen minutes, were given under the same conditions as for the previous series. The day following the final exposure, the periphery of the papilla of the right eye was slightly prominent and pinkish in color, but not abnormally so. The papilla of the left eye displayed a larger and deeper central excavation, but the periphery was not quite so salient as in the right eye. Abnormalities were not found in the anterior or posterior segments of the eye.

Rauch (1914), wishing to ascertain the minimal dose of roentgen rays compatible with the integrity of the eye, irradiated[30] the eyes of thirteen rabbits and noted the objective changes determined by inspection and ophthalmoscopic examination. Histologic studies were not undertaken. The total dose was always from 5 to 10 X[31]; some of the animals received this dose in one session, and others in two or three sessions at intervals of from one to nine days. One eye of each of two animals was irradiated for 216 seconds (10 X) in a single session. After seven and eleven days, respectively, conjunctivitis developed, which continued for thirteen and eighteen days, respectively. Twenty-nine days after exposure the vessels of the fundus of the irradiated eye of one rabbit were markedly dilated and tortuous. Diarrhea and anorexia also developed, and the animal died thirty-four days after exposure. Marked dilatation of the veins of the fundus in the irradiated eye of the second rabbit also was noted thirty days after exposure, and at the same time the animal became restless and irritable; these manifestations disappeared during the next ten days.

The right eye of one and the left eye of two rabbits were exposed to from 6 X to 10 X in three sessions of from seventy-two to 108 seconds, at intervals of from two to seven days. Conjunctivitis and slight ciliary injection appeared within one week, and loss of hair (eyelashes) within two weeks after the third exposure of the animal which had received a total dose of 10 X. The conjunctivitis diminished gradually. The cornea and iris remained unaffected, but dilatation of the retinal vessels was noted seventeen days after the third exposure. Anorexia, severe diarrhea, and paralysis of the hind legs supervened twenty-six days after the last exposure, and the animal was killed. Only slight conjunctivitis, without other changes, occurred in the two other animals.

[26] Probably adult animals.

[27] Roentgen rays generated at a voltage equivalent to a spark-gap of 10 cm.; intensity of current, 1.5 ma.; focal-skin distance, 12 cm.; filtration, 2 mm. of aluminium.

[28] Rays filtered through 4 mm. of aluminium; intensity of current, 4 ma.

[29] Duration of exposure, 15 minutes each time; rays filtered through 2 mm. of aluminium; intensity of current, 1.5 ma.

[30] The roentgen rays were generated at an unspecified voltage, but the hardness of the tube was given as 7–8 W. (probably Wehnelt). The focal-skin distance was 30 cm.; the milliamperage varied between 3 and 10.

[31] Kienböck photographic strip method.

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One eye of each of three rabbits was given 9 X or 10 X in two sessions, with an interval of three, two, and two days, respectively. Moderate conjunctivitis developed nine, twelve, and twelve days, respectively, after the second period of irradiation. Dilatation and tortuosity of the retinal veins were noted in only one of these three animals. One eye of a pregnant albino rabbit received 9 X in three sessions, with an interval of three days between the first and second, and seven days between the second and third sessions. Slight conjunctival irritation, evidenced by an increase in secretion, appeared ten days after the third exposure and disappeared a month later. Changes in the cornea or fundus were not observed. Two young rabbits, born soon after irradiation, were entirely normal. One eye of another rabbit received a dose of 10 X[32] in two sessions on successive days, after instillation of a 1 per cent solution of eosin into the conjunctival sac. A moderate conjunctival reaction appeared five days later, and marked dilatation of the retinal veins and loss of hair from the lids were noted twenty-four and twenty-seven days, respectively, after exposure. The eye was normal ten days later. One eye of each of three other rabbits received a dose of 5 X[33] in one session, but in one of these animals, the irradiation was preceded by the instillation of a 1 per cent solution of eosin. Slight conjunctival irritation, evidenced by increase in secretion, occurred in two animals twenty-one and fourteen days, respectively, after exposure, but this lasted only a few days. The cornea and fundus remained normal. In the third rabbit, in which irradiation had followed the instillation of eosin, moderate conjunctivitis developed one week later; greater dilatation of the retinal veins was noted twenty-seven days afterward, and this lasted about two weeks. The cornea of the exposed eye of all three animals remained unaffected. One eye of another rabbit received a dose of 2 X[34] and a month later the other eye of the same animal received a dose of 3 X,[35] but conjunctival or other abnormalities were not observed.

Pagenstecher (1916) irradiated the abdomen of seven rabbits, between nine and fifteen days after exposure to impregnation, with two or three times the erythema skin dose of roentgen rays.[36] Each animal was irradiated three times at intervals of two days, and the dose at each session was from 6.25 to 7 Holzknecht units, or from 12.5 to 14 X (Kienböck) units. Later five of the animals were found not to be pregnant or the fetus was dead. The two remaining animals were killed a few days before term; many of the fetuses were dead, but one fetus and three fetuses, respectively, were alive. In four of the six eyes of the living fetuses in one litter, and in one eye of the living fetus of another litter, typical retinal rosettes in otherwise normal eyes were noted on microscopic examination. A rosette-like fold of the retina was seen in one eye. These rosettes or folds were always situated around the point of entrance of the optic nerve, and were formed by cells of the granular layer. They were sometimes described as cone-shaped processes in the inner granular layer or as a group of cells from the granular layers, which extended to the retina or actually caused the inner surface of the retina to project toward the vitreous. Sometimes the group of cells was entirely separate from the granular layers, and the cells were arranged in a circle, giving the appearance of a rosette. In other eyes the rosette arrangement was distinct and was connected to the inner granular layer by a pedicle or lay within the granular layer. Occasionally two, or even three, such rosettes were found side by side in the same section. Pagenstecher concluded that such rosettes and folds in the granular layers of the retina in irradiated fetal eyes represented developmental deformities caused by the rays.

Terrien and Ledoux-Lebard (1919) reported two series of experiments carried out by

[32] 10 ma., 108 seconds each time.

[33] 10 ma., 108 seconds.

[34] 10 ma., 42 seconds.

[35] 10 ma., 66 seconds.

[36] The quality of the rays was 8 of the Bauer, or 12 of the Wehnelt, scale; the current was 2.5 to 3.0 ma.; the focal-skin distance, 15 cm.; the exposure, from nine to thirteen minutes; no filter was used

Terrien and Clunet. One eye of each of six rabbits[37] was exposed to from 10 to 15 Holzknecht units of roentgen rays[38] in from twenty to thirty minutes, and this was repeated every week for one month. Slight conjunctivitis developed one day after exposure and continued for a few days, but the cornea, iris, and retina remained normal. The right eye of each of four other rabbits[37] was likewise exposed to roentgen rays. In the first animal the rays were not filtered, their quality was 4 to 5 Benoist, and the quantitative dose, 1 Sabouraud-Noiré unit. In two others, the rays were filtered through 1 mm. and 3 mm. of aluminium, respectively, their quality was 7 to 8 Benoist and 8 to 9 Benoist, respectively, and the dose 1 Sabouraud-Noiré unit. In the fourth animal, 3 Sabouraud-Noiré units of rays 8 to 9 Benoist, filtered through 3 mm. of aluminium were employed. Only in the first rabbit, exposed to unfiltered roentgen rays, slight conjunctivitis and contraction of the pupil developed; this disappeared after a few days. The irradiated eye of the three other animals remained normal, except for depilation of the eyelids.

Jendralski (1922) investigated the action of roentgen rays on tuberculosis of the eye in an unstated number of rabbits. The anterior chamber of both eyes of each animal was inoculated[39] with a strain of *Mycobacterium tuberculosis* (human type) of rather low virulence. The period of incubation varied from animal to animal, but averaged between three and five weeks. The severity and extent of the inflammatory process also varied between moderate and severe swelling and hyperemia of the iris, with gelatinous and hemorrhagic exudation into the anterior chamber, haziness of the cornea, and the appearance in the iris of characteristic yellow, miliary nodules which often coalesced. Tuberculous infiltration around the point of inoculation in the cornea occurred in many of the animals, and this was often extensive. The tuberculous process increased for a time, after which it continued unchanged until the animal was killed from three to five months after inoculation. A tendency to spontaneous retrogression was noted in some instances. As soon as the tuberculous iritis was well developed one eye was exposed to roentgen rays[40] five times in two animals and three times in the remainder, at intervals of two or three weeks. Jendralski found it difficult in some animals to be certain that the differences noted in the condition of the two eyes really was due to irradiation. In general, he found that the tuberculous lesion, the swelling of the iris, and the inflammation of the eyeball disappeared rapidly from the irradiated eye when the condition before exposure to the rays was not too severe. When the miliary tubercles were numerous, the smaller nodules and the swelling of the iris disappeared rapidly, but the larger caseated nodules and the corneal infiltrate diminished, but did not disappear. The infection was always less severe in the irradiated than in the unirradiated eye. Evidence of bacterial destruction by the rays was not obtained.

Frogé (1922) exposed eight young rabbits from two to four weeks old to different doses of roentgen rays. In some animals one or the other side of the face was irradiated, while in others the rays were directed to the skull (supra-orbital) or to the eye itself. The right side of the face of the first rabbit was exposed to 30 Holzknecht units of radiation[41] in forty minutes. The left side of the face of the second rabbit received 50 Holzknecht units of roentgen rays[42] in sixty minutes. The supra-orbital region of the third rabbit received, in thirty-seven minutes, 35 Holzknecht units of roentgen rays under the same conditions as for the preceding animal. The right side of the face of the fourth rabbit was exposed to 20 Holz-

[37] Age not stated, but presumably adult.

[38] The other dosage factors were not given.

[39] The method of inoculation was not described, but the same quantity and the same dilution were used in all the animals.

[40] Symmetrie apparatus of Reiniger, Gebbert, and Schall; D. M. tube; hardness of tube, 13–14 (Wehnelt); intensity of current, 2 milliamperes; focal-skin distance, 30 cm.; filtration, 3 mm. aluminium; dose at each exposure, 1/2 normal dose (Sabouraud-Noiré), that is, about 5 X (Kienböck); time, 6 minutes.

[41] The rays were generated by a baby Coolidge tube operating in connection with an induction coil at a voltage equivalent to a spark-gap of 8 cm., with 3 ma. current, and without filter (very soft rays). The focal-skin distance was not mentioned.

[42] The rays were generated at a voltage equivalent to a spark-gap of 14 cm., with 3 ma. of current and with filtration 20/10. Focal-skin distance not given.

knecht units in twenty-five minutes.[42] The fifth animal was given, to the right side of the face, 50 Holzknecht units in sixty minutes. The right side of the face of the sixth rabbit received 12 Holzknecht units[43] in fifteen minutes. The left eye of the seventh animal received 5 Holzknecht units[44] in ten minutes. The right side of the face of the eighth rabbit (albino) received 50 Holzknecht units in sixty minutes. The mode of irradiation was not described. The irradiated eye of each animal was enucleated nine weeks, seven and a half months, eight weeks, four and a third months, eight days, six and a half months, six and two-thirds months, and eighteen days, respectively, after irradiation. The enucleated eyes were fixed in Bouin, Zenker, and formol bichromate solutions, imbedded in celloidin, and stained with hematin-eosin.

The two rabbits which had received 20 and 5 Holzknecht units, respectively, of filtered roentgen rays did not have radiodermatitis of the lids or any inflammation of the conjunctiva, but very slight epilation was noted in one animal. Pathologic changes were not found when the eyes of these animals were examined microscopically. Conjunctivitis, with irregular desquamation of epithelium, appeared in four of the rabbits which had received 30, 50, 12, and 50 Holzknecht units, respectively, of filtered or unfiltered rays. This was most marked in the two animals which had received 30 and 12 Holzknecht units, respectively, of unfiltered radiation, and was accompanied by keratitis, with desquamation or ulceration of the epithelium, fibrinous exudation and leucocytic infiltration of the aqueous humor, and slight iritis and slight polymorphonuclear leucocytic infiltration of the ciliary body. Shortly after the onset of conjunctivitis, epilation and radiodermatitis of the skin of the lids occurred, and the lids remained atrophic and parchment-like. The eyes of four rabbits manifested different degrees of cataract formation; the lenses were smaller than normal. Marked degeneration of the anterior epithelium was found in the exposed eye of only one rabbit, but this was apparently due to the severe inflammation which occurred in all the structures of this eye. The retina of the exposed eye of two of these animals had a peculiar folded appearance. In only one rabbit were any alterations found in the layer of rods and cones, and Frogé attributed them to the strong inflammatory reaction which occurred in this eye and not to irradiation, because a similar observation was not made in the irradiated eye of the other animals. Retardation in the development of the eye as a whole, as shown by the smaller size of the irradiated eye, was a constant observation when sufficient time had elapsed between irradiation and enucleation. Frogé concluded that strong doses of unfiltered roentgen rays may cause conjunctivitis and severe reaction in the lids, but that, otherwise, the effect of irradiation on the eyes of young animals is chiefly to retard the development of the eye as a whole and to cause in the lens degenerative changes that lead to cataract formation. Frogé added that the lens of adult animals did not exhibit such sensitiveness.

Rados and Schinz (1922) undertook to ascertain the effect on different parts of the eye of a large dose of roentgen rays given at one time and of several small doses given at short intervals. The animals (rabbits[45]) were anesthetized with somnifen and bound; the lids were kept open with retractors, and the roentgen-ray tube was placed over the cornea. To limit the field of irradiation to the eye the beam of rays was passed through a lead-glass tube which protected the remainder of the body. One eye of each of eight rabbits was subjected to a single irradiation[46] for one and a half, two and a half, three, four, five, six, six, and six hours, respectively, representing 650, 1000, 1300, 1700, 2100, 2600, 2600, and 2600 per cent, respec-

[42] The rays were generated by a Standard tube at a primary voltage of 75, with 5 ma. of current and no filtration. Focal-skin distance not given.

[43] The rays were generated by a Standard tube at a primary voltage of 88, with 5 ma. of current and filtration 20/10. Focal-skin distance not mentioned.

[45] Age and weight not given, but the animals were probably adult.

[46] Siemens special deep-therapy generator with oil inductor, operating on 50-period alternating current (1500 interruptions) in connection with Siemens hot-cathode tubes; voltage equivalent to a parallel spark-gap, between points, of 24 to 26 cm.; secondary current, 2.5 ma.; rays not filtered; focal-skin distance, 28 cm.

tively, of a human erythema dose.[47] The irradiated eye of the three animals which had been exposed for one and a half, two and a half and three hours, respectively (650, 1000 and 1300 per cent of a human erythema dose, respectively), remained wholly unaffected. In the eye of the rabbit irradiated for four hours (1700 per cent of a human erythema skin dose) epilation of the lids developed after a latent period of three weeks, and slight conjunctivitis and keratitis developed after four weeks. In the irradiated eye of the four remaining animals, one of which had received 2100 and the three others each 2600 per cent of a human erythema skin dose in five and six hours, respectively, total epilation of both eyelids and marked conjunctivitis developed after a latent period of three weeks, and one week later radiodermatitis of the lids developed, with ectropion, marked conjunctivitis, keratitis and ulceration in two instances. Evidence of injury to the lens was not found in any of the animals, in spite of the fact that the anterior pole of the lens in the irradiated eye of three of the rabbits received 1770 per cent, and the posterior pole 990 per cent, of a human erythema dose.[48]

One eye of each of four other rabbits was similarly exposed from two to nineteen times, at intervals of from two to four days, to individual doses varying between 20 and 165 per cent of the human erythema skin dose,[49] and the condition of the eye was observed for from three to one hundred twelve days. One animal received 165 per cent of the human erythema skin dose fifteen times in ninety days (total 2475 per cent of the human erythema skin dose). After six exposures in twenty-two days epilation of the lids and surrounding skin, and after eleven exposures in seventy-three days ulceration of the lids, developed. A second animal received 110 per cent of the human erythema skin dose nineteen times in one hundred twelve days. Total epilation of the lids and surrounding skin occurred after seven exposures in twenty-nine days, after which the animal died. A third animal received 20 per cent of the human erythema skin dose ten times in twenty-four days; 60 per cent of the human erythema skin dose twice in three days, and 110 per cent of the human erythema skin dose six times in twenty-five days (total of 980 per cent of the human erythema skin dose in fifty-two days). Ocular abnormalities were not observed after the first two series of exposures to a total of 320 per cent of the human erythema skin dose in twenty-seven days, but six weeks after the third series of irradiations (660 per cent of the human erythema skin dose in twenty-five days) marked conjunctivitis and superficial keratitis developed. One eye of a fourth rabbit received 20 per cent of the human erythema skin dose ten times in twenty-eight days, and 135 per cent of the human erythema skin dose seven times in twenty-two days (total dose, 1145 per cent of the human erythema skin dose in fifty-nine days). Slight, superficial keratitis was the only resulting abnormality.

Microscopic examination of the retina of the irradiated eyes, stained with hematoxylin-eosin, failed to disclose any deviation from the normal, and Rados and Schinz assumed that the reports of Birch-Hirschfeld and others to the contrary were unfounded. Leucocytic infiltration of the retina was observed in the animals with purulent inflammation of the ocular membranes, but this was regarded as due to the suppurative process and not to the specific action of roentgen rays. No evidence of cataract formation could be obtained, except in one rabbit with panophthalmitis, to which the cataract undoubtedly was due. Rados and Schinz concluded that: (1) the eye is comparatively insensitive to roentgen rays, much less sensitive than the skin; large doses of radiation can be given to the eye without risk; (2) the danger of inducing cataract is slight; (3) materials used to shield the eye are of value only for the protection they afford to the lids and palpebral conjunctiva; (4) the resistance of the retina

[47] The human erythema skin dose under these conditions required thirteen and five-tenths minutes, and the rabbit epilation dose, determined by irradiating the body of other animals, represented 450 per cent of the human erythema skin dose taken as 100 per cent.

[48] The absorption was measured in water with a large ionization chamber and a Wulf "einfadenelectrometer"; no attention was given to scattered radiation.

[49] Total dose between 120 and 2400 per cent of the human erythema skin dose.

accords with the known resistance of the central nervous system to roentgen rays, and (5) a single irradiation has more effect than the same dose given in several sessions at intervals.

Little and Bagg (1923) exposed the entire body of four adult female, and three adult male, brown mice to one-fifth of a human erythema dose of roentgen rays,[50] on each of five successive days. These mice were of a race sufficiently inbred to bring out latent defects, although no such defects had manifested themselves before irradiation. All the animals were in good health, and none was pregnant; nor were any young produced until more than ten weeks after exposure to the rays. The males were not tested separately. The beam of rays in each case was projected vertically downward, over and through the back of the animal.The irradiated mice showed no ill effects other than a temporary slowing-down of breeding. The descendants of these irradiated mice showed definite abnormalities, including acephaly, extreme pallor (such animals were born dead), shortening and upward deviation of the upper jaw, shortening of the foreface, irregular arrangement of the teeth, lesions in the cranial region, peculiar abnormalities of the eyes, and abnormal development of the legs and feet. The eyes were smaller than normal and had a sunken or shrunken appearance. An irregular, dry, scabbed area in the skin over or adjoining the eyeball was noted in most of the animals. This lesion varied greatly in degree, the skin over the whole eye being sometimes affected. The lens could sometimes be seen exposed in the center of this dried and scabbed area and was sometimes placed abnormally near the lower border of the scabbed area. As the animals grew older the affected eye failed to increase in size or degenerated further; such eyes were completely blind.

At birth the young from abnormal × abnormal matings showed the following possibilities: (1) both eyes clearly abnormal; (2) both eyes slightly abnormal; (3) one eye clearly, one slightly abnormal; (4) one eye clearly abnormal, one normal; (5) one eye slightly abnormal, one normal, and (6) both eyes normal. From one set of matings it appeared that the abnormality was recessive. Inheritance tests to ascertain if the lesions were transmitted through the sperm were then carried out by crossing one abnormal-eyed male with normal-eyed females of an unrelated race. The first hybrid generation had normal eyes. "F_2 produced by crossing F_1 inter se, and further similar crosses, gave a total of 113 normals and 29 abnormals. These abnormals and those of later hybrid generations bred together gave 16 abnormal in both eyes, 116 abnormal in one eye, and 36 normal (overlaps)." This was regarded as showing that the abnormality of the eye was inherited, and that such inheritance was essentially mendelian; some animals genetically abnormal-eyed were somatically normal-eyed.

The developmental abnormalities of the legs and feet varied from mere shortening to complete absence of the digits, and incomplete development and distortion of the legs often associated with discolored, hemorrhagic lesions. These deviations from the normal varied greatly in different animals and even in the same animal. Inheritance tests of this character gave results much the same as for the eye. Little and Bagg concluded that: (1) although macroscopic changes did not appear in the irradiated mice, the germ plasm had been affected; (2) this effect had resulted in genetic change, the inheritance of which was orderly and mendelian; (3) its somatic manifestation was abnormality of the optic nerves, eyes, and extremities, and (4) radium or roentgen rays should be used cautiously on human beings who are likely to become parents.

Jacoby (1924) investigated the ability of the cornea and retina to tolerate hard, filtered roentgen rays, the dose of which was expressed in terms of the human erythema skin dose. He also tried to determine whether injury to the cornea and retina by roentgen rays is the result of a direct effect on these structures or secondary to primary influence on the blood vessels. Five rabbits were bound (without anesthesia), the head was turned upward at an

[50] The roentgen rays were generated at a voltage equivalent to a spark-gap of 2.5 inches; focal-skin distance, 12 inches; no filtration; intensity of current, 10 ma.; duration of each exposure, 12 seconds.

angle of 45°, and the eyeball was luxated and fixed by means of a wire loop. Thus the upper half of the eyeball was approximately 5 mm. nearer to the target of the tube than the lower half, but this slight difference in distance did not affect the result in any way. Ophthalmoscopic examination before and during the luxation did not show a difference in the quantity of blood in the retinal vessels. The cornea was irrigated frequently with physiologic solution of sodium chloride to prevent drying. The roentgen tube was adjusted over the cornea by means of a lead glass tube 3.5 cm. in diameter. The surrounding region was protected by means of lead foil.

The right eye of the first rabbit was given 100 per cent of an erythema skin dose[51] in forty minutes,[52] but disturbance or abnormality was not observed during the ensuing three weeks. Irradiation was then repeated, but this also remained without effect. Four weeks after the second exposure, the same eye was given 200 per cent of an erythema skin dose in sixty minutes,[53] but this did not cause any change in the eye. The left eye of the same animal received 100 per cent of an erythema skin dose in thirty minutes,[53] but abnormality was not observed during the next five weeks. The same eye was then given 200 per cent of an erythema skin dose in forty-four minutes[54] and this was repeated six weeks later.[54] Evidence of keratitis in the form of fine dots scattered over the cornea appeared five days after the third irradiation; the lids and conjunctiva became greatly swollen, and an abundant mucous secretion exuded from the conjunctiva. The flecks on the surface of the cornea coalesced and formed ulcers, and the corneal parenchyma became cloudy. Pathologic changes were not found in the iris, lens, or fundus. The keratitis continued undiminished for five and a half months, when the eye was enucleated. The eyeball was fixed in formalin, the anterior segment with the cornea and iris was removed, the retina was carefully separated from the choroid, and both preparations, as well as a piece of conjunctiva and the lacrimal glands, were embedded in paraffin. The retina was stained with thionin and the other preparations with hematoxylin-eosin. The pathologic changes consisted in: (1) degeneration and thinning of the conjunctival and corneal epithelium, which, except around the limbus, was reduced to one or two layers of cells with indistinct outlines, vacuolized protoplasm, and deformed or disintegrated nuclei; (2) leucocytic infiltration, especially around the vessels in the vicinity of the limbus; (3) swelling of the endothelial cells, which had partly undergone vacuolar degeneration; (4) thickening of the muscularis and proliferation of the endothelial lining of occasional blood vessels in the iris, sometimes to the point of occluding the lumen, and (5) vacuolar degeneration of some of the ganglion cells of the retina, but without deviation from the normal in the other layers.

The left eye of the second rabbit was given 200 per cent of an erythema skin dose in sixty minutes.[55] Slight epilation of the lower lid occurred after four weeks, but the hair began to grow again two weeks later. Abnormality of the ocular structures themselves was not observed. The right eye of the same animal received 200 per cent of an erythema skin dose in eighty minutes,[56] and changes did not occur in this eye during the next six weeks. The same eye was then given 100 per cent of an erythema skin dose in fifty minutes[57] and, four and a half months later, 125 per cent of an erythema skin dose in fifty minutes,[58] but the eye preserved its integrity. The left eye of the third rabbit was given 250 per cent of an erythema skin dose in one hundred fifteen minutes.[57] This eye soon became hyperemic, and, after several

[51] Erythema skin dose measured by means of a Fürstenau intensimeter.

[52] Apex generator (Reiniger, Gebbert and Schall), with Watt boiling-water tube. Voltage equivalent to a parallel spark-gap of 31 cm.; secondary current, 1.5 to 1.8 ma.; filter, 4 mm. aluminium; focal-skin distance, 23 cm.

[53] Technical conditions the same as for the right eye, except that the rays were generated in a Müller boiling-water tube.

[54] Oil induction deep-therapy generator (Siemens and Halske), with Siemens-Coolidge tube: voltage equivalent to a parallel spark-gap of 38.5 cm.; secondary current, 2.5 to 3 ma.; filter, 0.5 mm. zinc and 3 mm. aluminium; focal-skin distance, 23 cm.

[55] Same technical conditions as for the left eye of the first animal.

[56] Same technical conditions as for the right eye of the first animal.

[57] Symmetrie generator (Reiniger, Gebbert and Schall), with self-hardening, boiling-water tube. Voltage equivalent to a parallel spark-gap of 38 cm.; filter, 0.5 mm. zinc; conditions otherwise the same as for the other animals.

days, the hyperemia was complicated by chemosis and abundant mucopurulent conjunctivitis. Distinct epilation appeared ten days after irradiation, and extensive radiodermatitis of the lids three weeks afterward. This inflammation of the lids subsided slowly, but required more than nine months to heal. Flecks on the cornea appeared twenty days after exposure; these coalesced, spread over the entire cornea, and formed dendritic erosions, which varied in shape and distribution from day to day. These disturbances continued for six months, but had almost disappeared at the end of nine months. In the meantime the hair on the lid had grown again. The iris and lens remained normal throughout. Some of the medullary rays in the fundus were well developed, and the papilla was well stained. The right eye of the fourth rabbit received 100 per cent of an erythema skin dose in ten minutes.[59] This animal died ten days after the exposure; ocular disturbances were not observed during the interval. The left eye of the fifth rabbit was given 300 per cent of an erythema skin dose in sixteen minutes.[60] Epilation appeared after two weeks and keratitis after three and a half weeks. The keratitis began to subside three and a half months later, but the lids remained devoid of hair.

Hyperemia and increase in secretion of the conjunctiva occurred one day after irradiation in all five animals, but this disappeared within one or two days. The earliest evidence of corneal irritation became perceptible only after instillation of fluorescein and examination with a corneal microscope as fine, irregular, green flecks, the shape and position of which changed each day. Hyperemia of the iris was never seen, and one drop of atropine was always sufficient to cause maximal dilatation of the pupil. Changes in the lens were not observed. Only the left eye of the third rabbit was enucleated and examined microscopically. The eyeball was immediately divided into four parts, one piece containing the cornea, one the papilla with the medullary rays, and the two others, each a piece of the lateral portion of the retina. The first three pieces were fixed in Zenker solution, and the other in formalin. After hardening in alcohol, the retina was carefully removed from the choroid and imbedded in paraffin. The corneal preparations were stained with hematoxylin-eosin, and the retina with thionin and acid-fuchsin-light-green. The corneal epithelium presented irregularities in cellular arrangement, especially of the basal cells, and variation in the number of layers. The retina showed scattered, high-grade degeneration of the ganglion cells and beginning degeneration of the inner granular layer.

From these results Jacoby deduced that the epilation dose in the rabbit is approximately 2 erythema skin doses; the injurious dose for the cornea is approximately two and a half times the erythema skin dose; the latent period for epilation is from two to four weeks, and for keratitis three to five weeks, after the first irradiation, but this period decreases when irradiation is repeated; one erythema skin dose may be repeated at intervals of three or four weeks without injury to the lids or cornea. Jacoby thought Rados and Schinz wrong in assuming that the cornea can tolerate 1,700 per cent of an erythema skin dose or that it requires 450 per cent of an erythema skin dose to cause epilation of the lids.

Sabbadini (1924) undertook to study the effect of secondary roentgen rays on infected ulcers of the cornea. He first lacerated the corneal epithelium of guinea pigs by means of a Graefe knife and then spread over the lesion one or two loopfuls of a bacterial emulsion. In addition to the corneal lesion the bulbar conjunctiva was transfixed and the bacterial emulsion spread over the lesion; or the bacterial emulsion, diluted in physiologic solution of sodium chloride in the proportion of one loopful for each cubic centimeter of solution, was injected beneath the conjunctiva. The bacteria used were: *Staphylococcus aureus* isolated from a case of panophthalmitis, hemolytic streptococci isolated from a deep phlegmon in the

[58] Same technical conditions as for the right eye of the first animal.

[59] Same technical conditions as for the left eye of the first rabbit, except that the rays were not filtered.

[60] Oil induction deep-therapy generator (Siemens and Halske); voltage equivalent to a parallel spark-gap of 38.5 cm.; secondary current, 2.5 to 3 ma.; filter, 0.5 mm. zinc and 3 mm. aluminium; focal-skin distance, 23 cm.

cervical region, and pyogenic streptococci from a large ulcer of the cornea, with hypopyon. In control animals small ulcers produced and infected in this manner healed in from one to fifteen days, but the more extensive ulcerations led rapidly to panophthalmitis. Animals with lesions in full evolution were exposed to roentgen rays,[61] with a tampon of cotton impregnated either with a 50 per cent solution of double citrate of copper and ammonia or a 1:1,000 solution of double citrate of bismuth and sodium between the lids and in contact with the cornea. Corneal ulcerations without hypopyon healed in five or six days, and ulceration with hypopyon in from twelve to sixteen days. Actual panophthalmitis was not influenced.

Stock (1926) injected an unspecified dose of *Bacillus tuberculosis* into the blood stream of a number of animals,[62] and tuberculous uveitis resulted. The infected eyes were then exposed to roentgen rays[63] in doses approximating 100 per cent of the erythema skin dose, and the eyes were examined four, eight, and twelve hours later. The first change noted in the tubercles was disintegration of the lymphocytes, followed by a distinct tendency of the lesions to retrogress and to be replaced by scar tissue.

Radium. Birch-Hirschfeld (1904) tested the effect of radium by exposing one eye, in each of one young and four adult rabbits, to the action of 20 mg. of radium bromide in a capsule of ebonite closed with a plate of mica. This capsule was attached to the eyelids for from two to six hours. The other eye of each animal was left unexposed to serve as a control. The left eye of one adult animal was thus irradiated for two hours, and, after a latent period of eight days, radium dermatitis with loss of hair developed; ulceration occurred later. Mucopurulent conjunctivitis, interstitial keratitis, and fading of the color of the pupil were noted four weeks after the exposure.

In the portion of the eyelid corresponding to the position of the radium, microscopic examination revealed deficient staining, swelling and actual destruction of the epithelial cells. This area was covered with a scab raised by dense, leucocytic infiltration extending deep into the subcutaneous tissue and forcing apart, and causing atrophy of, some of the fibers of the orbicularis. Absence of hair follicles and slight swelling and proliferation of the endothelium of the blood vessels were observed in the irradiated portion of the lid. In the conjunctiva were found marked swelling of the epithelial cells, especially in the basal layer, where the cells were crowded and club-shaped and the nuclei rod-shaped or irregular; irregularity of the cell layers and slight leucocytic infiltration, and partial swelling and proliferation of the cells of the intima of the blood vessels. In the cornea were found swelling and vacuolization of the cells of the middle and basal layers; numerous binucleated cells and occasional mitotic figures around the periphery, and slight infiltration and dilatation of the interfibrillar spaces. In the iris were found occasional disintegration of the processes of the stroma pigment cells; distention of the blood vessels, and beginning vacuolization of the intima; swelling of the posterior layer of pigment, and hyperemia of the ciliary body. In the retina were found slight loosening of the granular layers and the layer of nerve fibers; degeneration of the ganglion cells with intense blue staining of the protoplasm of some of the cells, and faded blue staining of other cells, with extensive vacuolization; irregular shrivelling of nuclei; normal appearance of some of the ganglion cells; degeneration of the inner and outer granular layers evidenced by disintegration, irregular shape and size, and loss of transverse striation of the granules, and absence of inflammatory changes in the pigment epithelium or retinal vessels. In the optic nerve (Marchi preparations) was found myelin degeneration of some of the fibers extending to the periphery of the medullary rays.

One eye of an old, white rabbit was irradiated in the same manner for two hours. After a latent period of twelve days, moderate conjunctivitis developed, but the cornea, iris, and fundus remained normal throughout the one hundred and twenty day period of observation.

[61] The dose was not described.
[62] The number, age, weight, and sex of the animals were not mentioned.
[63] The quality of the rays was not described.

Microscopic examination disclosed several foci of leucocytic infiltration in the deep layers of the conjunctiva, especially around the limbus. All the other structures of the irradiated eye were normal. One eye of a young, white rabbit was likewise irradiated for three hours. Conjunctivitis, ciliary injection, hyperemia of the iris, slight haziness of the cornea, but no changes in the fundus had developed three hours after exposure to radium, when the animal was killed. In general, the changes noted resembled those found in the first animal, except that they were less pronounced and the optic nerve and papilla were normal.

One eye of an old, gray rabbit was similarly irradiated for five hours. Conjunctivitis, pericorneal injection, dense clouding of the cornea, and hyperemia of the iris appeared after a latent period of sixteen days. These symptoms subsided after several weeks, but moderate conjunctivitis, punctate foci in the cornea, and slight hyperemia of the iris were still present eighty-nine days after irradiation, when the animal was killed. The color of the pupil had become lighter and the medullary wings indistinct. Microscopically, moderate leucocytic infiltration of the conjunctiva, moderate dilatation of the interfibrillar spaces in the anterior layers of the cornea, the presence in such spaces of rounded elements suggesting migratory cells, and irregularity of the corneal corpuscles were noted. The posterior layers of the cornea and Descemet's membrane were normal. The anterior chamber was filled with a fibrinous exudate containing occasional leucocytes. There was slight swelling and infiltration of the iris, and its vessels, the intima of which was partly swollen or thickened, were markedly distended. The pigment cells of the stroma were clumped and irregular in outline and their processes partly degenerated; the posterior layer of pigment was in part swollen. The ciliary body exhibited changes similar to those in the iris. The ganglion cells in the retina were largely normal, but some showed vacuoles, shrivelling of the nucleus, and cellular disintegration. The granules of the inner layer were more loosened and degenerated than those of the outer layer. The retinal vessels, pigment epithelium, and choroid were normal, but the optic nerve and medullary rays showed great myelin degeneration.

One eye of an old, white rabbit was exposed to radium for six hours. Conjunctivitis, haziness of the cornea, and hyperemia of the iris became perceptible after a latent period of seven days, and this was soon followed by epilation of a portion of the lower lid, on which a scab had formed. These inflammatory manifestations subsided gradually, and fresh epithelium crept in to repair the ulcer, but this area of the eyelid remained devoid of hair. Ophthalmoscopic examination, several weeks after irradiation, showed a grayish-white papilla and indistinct medullary rays. The animal was killed ninety-seven days after exposure to radium. The only changes in the eye were: vacuolization of the ganglion cells of the retina, indistinct shrivelling of the protoplasm and nucleus, loosening and disintegration of the granules, pronounced myelin degeneration of the optic nerve, and hyperemia of the choroid. Birch-Hirschfeld concluded that: (1) the comparative effect of different doses could not be established, he attributed the difference noted to individual factors, such as age; (2) the cellular changes in the conjunctiva, cornea, and iris caused by radium resembled those caused by roentgen rays, as inflammation, effort at repair, degeneration and absorption or final regeneration of cells; (3) changes in the walls of the blood vessels were noted only when the period of observation was long; (4) the injury and degeneration of the epithelium of the cornea was a direct effect of irradiation; (5) the lens was never affected; (6) degenerative changes occurred in the retina, but these were not specific, because similar abnormalities occur after experimental quinine and Felix amaurosis, methyl alcohol amaurosis, after division of the optic nerve, and also as postmortem changes; (7) the retinal changes also were due to the direct effect of the rays and were not secondary to alterations in the blood vessels induced by the rays, and (8) the degeneration of the optic nerve was secondary to the action of the rays on the cells of the retina. No explanation was offered for the unequal behavior of the ganglion cells, and a similar difference was noted after experimental poisoning with methyl alcohol; it was also noted clinically with chronic nicotine-alcohol amblyopia.

In an effort to determine the first morphologically demonstrable changes in the cells of the retina, "the retina of a freshly enucleated rabbit eye was divided into several sectors, loosened from the choroid, and spread on a slide covered with vitreous." Some of the preparations were exposed to radium,[64] while another piece of retina on the same glass was not irradiated. After staining with dilute methylene blue (0.05 per cent), ten irradiated and ten unexposed preparations were compared from time to time. The ganglion cells and nerve fibers in the irradiated and nonirradiated specimens were stained simultaneously. Abnormality was not found in specimens exposed for from five to twenty minutes, but protoplasmic vacuolization, and irregularity and shrivelling of the nucleus were noted in specimens exposed for from twenty to forty-five minutes. Abnormal ganglion cells were occasionally found in the unirradiated specimens, and the cellular changes in the exposed specimens were not uniform, but the difference between the exposed and unexposed specimens was sufficient for Birch-Hirschfeld to attribute the difference to irradiation.

Milroy (1905) sought to ascertain if the fluorescence set up by radium in the developing eye produces the same effect on the retina as ordinary light, and if there is any hindrance to the development of the eye or any alteration in its tissue elements when chick embryos are developed with a radium capsule placed over the shell of the egg. He applied closely over the eggs, in the incubator, a small tripod, on which was placed a vulcanite capsule containing 20 mg. of radium bromide.[65] The floor of the vulcanite capsule was formed by a thin mica plate which alone intervened between the radium salt and the shell of the egg. The eggs, with the tripod carrying the radium, were then placed in a thick-walled lead chamber and kept in a dark incubator for seven, eight, ten, fifteen, and eighteen days, respectively. The shell and membrane of the eggs were next carefully removed, and the eggs were exposed to the direct action of the rays for from one to three hours. After this the eyes of some embryos were placed in fixing solution,[66] while the eyes of other embryos were dissociated in weak osmic acid solution.

Discoloration of the egg-shell membrane was noted in all cases, and in many cases the odor of trimethylamine also was perceptible. The eye of the embryo irradiated for seven days had the same general appearance as the eye of unirradiated embryos developed under ordinary conditions, but there was marked degeneration, especially in the retina, and also in the other tissues of the eye. The lens appeared normal, but marked fluorescence had been set up in it. The retina was much thinner than normal, and this thinning appeared to be due to general degeneration of the protoplasm of all the cells of the retina. The pigment cells were swollen, their granules were scattered diffusely throughout, and many granules had been "driven out into the tissue behind." However, there were no pigment protrusions. The nuclei of the cells of the retina did not show the usual stratified arrangement but were massed together irregularly. Mitosis was noted in the cells at the back of the retina; the mitotic figures were fairly numerous, but they were made out with difficulty because of a "falling together of the chromosomes." The mesoblasts surrounding the retina also were broken down. After irradiation for longer periods, disintegration of the ganglion cells and degeneration of the optic nerve fibers were marked and yet development proceeded. The formation of rods and cones was observed at the fifteenth, eighteenth, and twentieth days, but these elements degenerated as their development advanced. The effect of radium seemed greatest on the loose cytoplasm of cells which had reached fairly complete development. At about the fifteenth day a large amount of pigment was present in the cells of the pigment layer, but it was distributed loosely throughout the cells and behind the rows of cells. The rod and cone elements ap-

[64] Quantity, distance, filtration and so forth, not stated. The irradiation varied between five and forty-five minutes.

[65] Other than the vulcanite and mica no mention of filtration was made.

[66] Corrosive sublimate 4 gm.; sodium chloride, 0.5 gm. in 100 c.c. of 50 per cent alcohol. After fixation, the eyes were carried through paraffin and the sections stained by Heidenhain's hematoxylin iron-alum method, in other cases by Nissl's method or by eosin-hematoxylin.

peared as cuticular projections beyond the external limiting membrane, but they were more broken down than in the unirradiated eye at the same stage of development. The external nuclear layer was composed of large, vesicular nuclei, and the protoplasmic strands were broken into small fragments. Owing to disintegration of the fibrillar network, the external molecular layer was abnormally granular. Advanced degenerative changes were found in the internal nuclear layer; the nuclear outlines were faint and the cellular processes so disorganized that they could not be traced beyond the cell bodies. The changes in the internal molecular layer were the same as in the external. The ganglion cells were vacuolated, often shrunken and collapsed, and their processes could not be traced much beyond the cells themselves. The optic nerve fibers were disintegrated, and the strands held a large amount of granular débris.

The lens and the muscle fibers were affected the least, whereas the greatest changes were found in the cells of the retina; but at no period of development did radium cause any reaction in the cells which normally respond to light. The pigment cells developed normally, but the spicules were "driven out partly into the tissues lying behind the retina." This was true at all stages and in all the specimens, but a true protrusion of pigment-holding processes was never found, nor a contraction of rod and cone fibers such as occurs after light stimulus. Milroy thought these effects must have been due chiefly to the gamma rays, but perhaps also to the beta rays, of radium.

London (1906) exposed three growing rabbits, two male and one female, weighing 1.095 kg., 1.313 kg., and 1.028 kg., respectively, to the action of radium. The animals were kept in a cage 43 cm. long, 41 cm. wide and 31 cm. high. Over the center of the roof of the cage a box,[67] containing 26 cg.[68] of radium bromide, was placed, and this box was removed from time to time for a few hours to as long as seven days[69] for use in other experiments. The rabbits remained in normal condition for fifteen days after irradiation; then abnormalities of the skin, nervous system, eyes, sexual function, and general metabolism developed. As far as the eyes were concerned, repeated ophthalmoscopic examination disclosed only slight alterations[70] in the cornea and crystalline lens, but marked central retinitis. One rabbit had central neuritis. Pronounced ectropion from radiodermatitis of the lids occurred in one animal. Shortly before death the eyelids closed and were covered with dried secretion. The retinal changes varied in degree, and the greater effect on the reticular membrane and on the nerve proved to London that the vessels and nerve are especially sensitive to the rays.

Roselli (1907), using 1 mg. of radium at a distance of 3 or 4 mm., without any protection, exposed one eye of a rabbit for from twenty to thirty minutes, but carefully shielded the other eye. Shortly afterward[71] both eyes were removed completely, fixed and imbedded, and sections from the irradiated and unirradiated eyes were examined microscopically. In a second experiment the same quantity of radium was applied to one eye at the same distance for thirty minutes on two successive days. In a third experiment, the radium was applied to one eye of an unstated number of rabbits for thirty minutes on each of three successive days. In this instance an interval of from eight to fifteen days was allowed to elapse before the eyes were removed and examined. Roselli did not find pathologic changes in any of the eyes irradiated under the conditions stated.

Zelenkovsky (1908) exposed the eye of a rabbit to the action of 10 and 30 mg. of radium, and one of his own eyes to 1 and 10 mg., respectively. The 1 mg. unit was placed in a small, straight tube[72] 5 mm. long and 2 mm. in diameter, soldered to a glass rod. The 10 mg. unit was placed in the curved end of a glass tube 2 mm. in diameter, with walls 0.3 mm. thick; the

[67] The nature of this box and its filtering power were not specified.
[68] Probably 26 milligrams; quantity stated differently in different accounts.
[69] The gross and net duration of exposure were not given.
[70] These alterations were not described.
[71] Interval not stated.
[72] Character and thickness of tube not mentioned.

radium occupied 1 cm. of the lumen of the tube, the remainder of which was filled with wax. In the case of the rabbit the rays were made to act on the eyeball directly from a distance of 2 or 3 cm., with the eyelids held apart by a special retractor. Exposure of the eye of the rabbit to 30 mg. of radium for half an hour to one hour led to desquamation of the superficial layers and cellular degeneration in the deeper layers of the cornea, with inflammatory infiltration, fibrinous exudation into the anterior chamber, hyperemia of the iris and ciliary body, and degeneration of the ganglion cells of the retina. Exposure to 10 mg. for half an hour several times produced much the same effect. A single exposure to 30 mg. of radium for fifteen minutes did not cause perceptible changes. Exposure of the eye to 10 mg. every two or three days for ten minutes at each session also remained without effect. Zelenkowsky found that exposure of his own eye to 1 or even 10 mg. ten times for ten minutes every other day caused only slight hyperemia of the conjunctiva. He concluded that the radiosensitiveness of the eye is proportional to the quantity of radium and to the length of its action; that degenerative changes, with clinical manifestations, may be induced in the retina; that such retinal changes are a direct effect of irradiation, and that clinical evidence of ocular reaction manifests itself only after a latent period of about two weeks.

Flemming and Krusius (1911) investigated the action of radium and mesothorium on tuberculous processes in the eye by introducing into the cornea or anterior chamber of more than 100 rabbits 0.05 c.c. of an emulsion of dried tubercle bacilli (containing 0.000005 mg. of bacilli of the bovine type) in bouillon culture, with a physiologic solution of sodium chloride in a weight relation of 1:10,000,000. One eye of each animal was left unirradiated to serve as a control; tuberculous lesions developed in all control eyes after precisely the same incubation period. The animals were divided into several series apparently in order to determine the effect of radiant energy on: (1) the bacterial emulsion and its subsequent infective power; (2) the normal eye and the course of the subsequent tuberculous infection; (3) the infected eye during the period of incubation, and (4) the bacteria in the eye after the clinical outbreak of the disease. An attempt was made to estimate the relative influence of body resistance, radiant energy, and bacteria, and to determine if the therapeutic effect noted was due to injurious action on the bacteria, to increase in general resistance, or to injurious effect on both the body and the bacteria. The criteria by which the results were judged were the length of the incubation period and the time between the clinical appearance of the tuberculous process and perforation of the eyeball.

Two and six-tenths milligrams of radium, separated from the eye by aluminium 0.02 mm. thick, and 12 mg. of mesothorium, separated from the eye by aluminium 0.2 mm. thick were used for irradiation. Radium and mesothorium were also used in solution; this was allowed to dry on a surface measuring 1.3 to 1.4 for radium, and 1 to 2 for mesothorium.[73]

A description of the experiments and of the results in each animal or group of animals was not given. Flemming and Krusius merely stated that: (1) the action of radium on the isolated bacteria was to increase the perforation time to three weeks, without any change in the incubation period, while mesothorium increased the period of incubation; (2) the effect of mesothorium on the eye before incubation was to extend the perforation time several weeks, without any change in the incubation period; (3) exposure of the inoculated eye to radium during the incubation period extended the perforation time about four weeks, but did not affect the period of incubation; (4) exposure to mesothorium increased both the perforation time and the incubation period, and (5) both radium and mesothorium, when used to irradiate the clinically diseased eye, increased the incubation and perforation time. Flemming and Krusius concluded that radium and mesothorium have a certain influence on the organism and on the infected eye, but that this is slight in comparison with the marked bactericidal action of the sun at high altitude, which they also tested. Without submitting any evi-

[73] This refers to the radioactivity of the dried surfaces, but further details were not given.

dence they added that, besides the effect of radiation on the bacillus of tuberculosis, radium and mesothorium also act on the body and especially on the blood vessels.

Chalupecky (1911) exposed the eyes of rabbits[74] to 5 mg. of radium salt enclosed in a capsule[75] covered with mica. The capsule was attached to the eye of each animal for one or two hours daily, on successive days or at intervals of several days. Inflammation of the conjunctiva appeared after about eight hours of irradiation; after exposure to radium for fifteen hours the palpebral conjunctiva became greatly swollen and covered with "a superficial coating." The cornea was cloudy and the pupil contracted, but the iris was unaffected and ophthalmoscopic examination was negative. Further exposure to radium did not increase the foregoing disturbances. The animals were then decapitated, and the irradiated eye and lids were examined microscopically. The conjunctival epithelium was irregular and in places absent. Irregularity of the corneal layers made this structure appear sagged, and this was accompanied by "slight infiltration and numerous small lacunae, as if the layers had been forcibly separated." A distinct increase in the fixed corpuscles of the cornea also was noted, but there were no newly formed blood vessels. Descemet's membrane, and the iris, lens, and retina were normal. Chalupecky attributed the slight changes in the conjunctiva and cornea to the small quantity of radium.

The action of radioactive water on the eye also was tested by injecting beneath the conjunctiva 1 c.c. of radioactive water made from uranium pitch and having about the same radioactive strength as "hot Mühlbrunn."[76] This fluid was absorbed within twenty-four hours, and the eye gave no external or internal evidence of reaction. Further injections[77] of from 0.5 to 1.5 c.c. of radioactive water containing 122 M. u. for each liter were made beneath the conjunctiva and also through the sclera, directly into the vitreous. The fluid injected under the conjunctiva was absorbed within twenty-four hours, almost without reaction. The injections into the posterior chamber were followed by clouding of the cornea and vitreous and by increase in the intraocular tension. The cloudiness of the cornea and vitreous disappeared in a few days, after which ophthalmoscopic examination showed delicate strands adherent to the point of puncture in the vitreous or partial detachment of the retina around this point. Haziness of the lens was noted only once, and this was regarded as due to injury to the posterior surface of the lens by the puncture.

Chalupecky explained that these results were essentially the same as those obtained by injecting plain sterile water and that this indicated a rapid disappearance of the emanation from the body. This was further substantiated by his observation that the injected but otherwise intact eye, when enucleated immediately after decapitation of the animal and examined with an electroscope, failed to give any evidence of radioactivity. The conjunctiva removed from the part of the eye surrounding the point of puncture also failed to give clear signs of radioactivity. The eye, into the vitreous of which radioactive water had been injected, also was tested electroscopically. The membranes did not show radioactivity, but the vitreous itself was definitely, although slightly, radioactive. Chalupecky attempted to account for the electroscopic data by stating that the alpha rays in the injected radioactive water could not penetrate the ocular membranes, were retained in the vitreous, and, therefore, could not affect the electroscope until the eye was opened and the vitreous exposed. The beta rays had not had time to act, because the animal had been killed so soon after injection.

Flemming (1913), after determining the effect of a preparation of radium on the normal human skin, investigated the effect of the same preparation on the normal eye and on tuberculous lesions of the eye. Ten milligrams of radium bromide 90 per cent pure was placed on a

[74] Number and age not stated.
[75] Nature of capsule not mentioned.
[76] According to Falta, Mühlbrunn is credited with a radioactivity of 3.5 M. u. (probably Mache units) per liter.
[77] The number of such injections was not stated, and no mention was made of control conditions.

piece of linen, dissolved in a few drops of distilled water, and changed to the less soluble carbonate by adding ammonium carbonate; this linen was then mounted in a frame, covered with a gelatin composition, then with paraffin, and finally with 0.01 mm. of aluminium.[78] The back was protected with lead. The radioactivity of this applicator, measured with an electroscope after the product had become stable, was found to be only 4.04 mg. The preparation contained 10 per cent of alpha rays, 70 per cent of beta rays, and 20 per cent of gamma rays. The radioactivity of the preparation diminished gradually to 2.6 mg. A second preparation containing 12 mg. of mesothorium, filtered through 0.1 mm. of aluminium, was employed in the same manner. A third preparation, containing 10 mg. of polonium spread on a piece of copper 10 by 20 mm., was used for some of the experiments.

The action of these radioactive sources on the normal eye, and on aseptic external injuries and infected wounds of the eye, was then tested in a number of rabbits and one guinea pig. The applicator, enclosed in gutta percha, was placed in contact with the cornea, under the lids, and sutured in position. Exposure for two hours to 4.8 mg. of radium distributed evenly over the eye did not provoke clouding of the cornea. The cornea also tolerated exposure for thirty minutes to 12 mg. of mesothorium when evenly distributed. Three milligrams of radium sutured beneath the lower lid, in immediate contact with the cornea and left in place for twenty hours, caused superficial keratitis, which required six weeks to subside. Microscopic examination of this eye six months later did not disclose any perceptible changes. Twelve milligrams of mesothorium spread evenly over the anterior portion of the eyeball and allowed to act for three hours caused superficial inflammation of the cornea lasting one week; exposure for eight hours caused ulceration of the cornea which healed after eight weeks, but left permanent scars. Hypopyon and corneal ulceration were observed in one guinea pig three weeks after exposure; the animal died soon afterward; the cause of death was not clear.

Attempts were made to determine the effect of irradiation on eyes injured experimentally and subsequently infected, but the early death of some of the animals prevented accurate observations. In others, however, healing was more rapid in the irradiated than in the unirradiated eye. To test the effect of irradiation on the conjunctiva and cornea irritated by chemicals, 0.1 c.c. of a 6.6 per cent solution of dionin was injected into the substance of the cornea of both eyes at the upper part of the limbus; one eye was exposed for from ten to twenty minutes to the action of 2 mg. of radium or 12 mg. of mesothorium, either before or after the injection of dionin. The infiltrate disappeared completely in a few days regardless of irradiation, and exposure up to twenty minutes had no apparent influence on the conjunctiva or cornea. Changes occurred in the skin of the lids, but these changes were not described.

Abelsdorff (1914) studied the action of thorium X on the different elements of the eye in forty-two rabbits. To eliminate variability of absorption and irregularity of effect by variation in distance between the radioactive substance and the surface of the eye, he injected into the eye an aqueous solution of thorium X. The amount of solution injected was 0.1 c.c., equivalent to the gamma rays emitted by from 0.017 to 0.15 mg. of radium bromide. Control conditions were provided by injecting into the eyes of other rabbits a similar quantity of an aqueous solution of thorium X, which had been allowed to stand for several weeks and which had, therefore, become practically inactive. This sterilized and chemically neutral, inactive solution was tolerated as well as physiologic solution of sodium chloride. The injection of an acid solution into the anterior chamber caused delicate clouding of the cornea and slight iritis, but this disappeared in a few days. After anesthetizing the eye with cocaine, from 0.1 to 0.2 c.c. of the aqueous humor was withdrawn from the anterior chamber and was replaced by a corresponding amount of thorium X solution. Small doses, equivalent to 0.017 mg. of radium bromide, did not affect the eye, except for bleaching of the iris after two or three days; the cornea remained clear. Larger doses, equivalent to 0.1 mg. or more of radium bro-

[78] The preparation was distributed over a surface 1.1 by 1.3 cm.

mide, caused iritis in from twenty-four to forty-eight hours; the pupil became smaller and showed posterior synechiae; small petechial hemorrhages sometimes appeared on the surface of the iris; parenchymatous inflammation of the cornea developed, and the anterior chamber increased in depth. These inflammatory manifestations subsided in a few weeks. The eye was then free from reaction; the cornea was clear except for a few cloudy areas, the pupil was larger than in the other eye, and the iris was completely lacking in color. The lens remained transparent and the fundus normal. The inflammatory symptoms sometimes included purulent conjunctivitis associated with ectropion of the lower lid or with deep ulceration of the cornea, which usually healed without perforation, but left a thick scar. The most constant effect was loss of color of the iris.

The microscopic appearance of eyes thus injected with thorium X was characterized by clumping of the pigment granules and degeneration of the chromatophores of the iris; increase in "Klumpenzellen"; marked hyperemia and petechial hemorrhages of the iris and ciliary body, which Abelsdorff regarded as a direct result of injection of thorium, because the vesicles occurring after ordinary puncture of the anterior chamber disappeared within a week whereas those seen after injection of thorium X were still present several weeks later. The hyperemia of the iris subsided in a few weeks, but, except after small doses, the iris underwent progressive atrophy. The stroma became less cellular and was finally represented by thickened processes. The connective tissue also disappeared. The muscular coat of the sphincter was thinned, and only occasional fibrils remained to indicate what had been iris tissue around the pupil. Part of the endothelium of the vessels of the iris was destroyed, and these changes affected the intima and the media. The corneal endothelium was shrivelled or lacking in places; the cells of the choroid were increased within the lymph spaces, and the fibrils were loosened. Leucocytic infiltration of the choroidal borders extended into the adjacent conjunctiva and sclera; occasional eosinophiles, as well as newly formed vessels extending from the edge, and loss of staining quality during the late stage of reaction were noted. Increase in the albumin content of the aqueous and vitreous humors was attributed to hyperemia of the ciliary body and disappeared as the hyperemia subsided.

From a few drops to 0.1 c.c. of a solution of thorium X was injected from above or below into the vitreous of an unstated number of rabbits. This was followed, after from a few hours to one or two days, by slight cloudiness of the vitreous and a circumscribed exudate in or behind the retina, which later sometimes became loosened. The retinal vessels soon became narrow or even interrupted in places. Hemorrhages studded and beclouded the radiation of the medullary fibers. Later, slight atrophy of the medullary wings gave the optic nerve the appearance of a round disk with scanty vessels. After from one to one and a half months, foci of terminal chorioretinitis in the form of white flecks studded with black pigment were visible in the fundus. The lens generally remained clear, although cloudy areas in the posterior corticalis, such as occur in severe intraocular disease, were sometimes seen several weeks after the injection. The first changes noted were: decoloration of the iris; albuminous masses in the vitreous and in the posterior chamber; hyperemia of the choroid extending to the ciliary body; fibrinous exudation at the posterior pole of the eye separating the retina from the choroid; partial preservation and partial sloughing and accumulation of the pigment epithelium into gland-like formations, and hydropic swelling of the necrotic epithelium; disappearance of the rod and cone layer from the retina; falling away of the external granules, cavity formation in the intergranular layer, and filling of the cavities with thready clots; edema of the loosened and swollen layers of the nerve fibers; numerous hemorrhages on the inner surface of the retina; partial absence of endothelium from or leucocytic and erythrocytic thrombosis in the retinal vessels around the papilla, and normal appearance of the remainder of the retina. Later the choroidal vessels underwent sclerosis, and connectivet issue atrophy gave the choroid the aspect of a thin membrane. Degeneration of the optic nerve

involving the medullary wings was limited to the anterior section, where occasional vesicles filled with exudate appeared on the ciliary processes eight or ten days after injection. Degeneration of the stroma cells of the iris was usually limited to the anterior marginal layer and to the numerous Klumpenzellen. The cornea was intact, except for circumscribed swelling and shrivelling of the endothelial cells. Masses of homogeneous, necrotic material and other masses of calcareous material were found in cavities between the conjunctiva and sclera, surrounded by a ring of lymphocytic infiltration, which extended into the fibers of the superior rectus muscle. This corresponded to the puncture points of injection.

Abelsdorff concluded that: (1) small doses of thorium X caused reparable injury to the retinal vessels, only slight changes in the retina itself, and extensive degeneration of the iris; (2) the inflammatory infiltration of the optic nerve was not due to the direct action of the rays, but was secondary to the initial disturbance in circulation; (3) the necrosis and calcification of the conjunctival and subconjunctival tissues were due to the prolonged action of the rays; (4) the late cicatrization of the iris after injection of thorium X into the vitreous was due to injury to the chromatophores but not to the posterior pigment layer of the iris by thorium solution passing into the anterior chamber; (5) the lens is not readily influenced by irradiation, and (6) the choroid is more susceptible than the retina, and all the pathologic changes described were due chiefly to the alpha and beta rays.

Stargardt (1915) tested the effect of thorium X on the ocular structures by injecting into the anterior chamber of one eye of two adult rabbits, under local anesthesia, 0.05 c.c. and 0.025 c.c. of a neutral solution of thorium X diluted ten times; 1 c.c. of this solution contained as much gamma radiation as 0.9 mg. of radium bromide.[79] The injections were made with a fine Pravaz cannula; this was passed through the cornea as transversely as possible, the aqueous humor was allowed to drain out, the thorium X solution was then injected slowly, and the cannula was withdrawn quickly to prevent escape of the injected fluid. The two animals were killed by a blow to the back of the neck, thirty-five and one hundred eighty-eight days, respectively, after the injection. The eyes were fixed in formalin and Birch-Hirschfeld's mixture. The immediate action of the solution on the eye of the first rabbit was slight injection of the ocular conjunctiva and a small fleck of fibrin in the anterior chamber. Twenty-four hours later the injected eye appeared normal. Slight decoloration of the iris became perceptible in one of the animals fourteen days after the injection, and reached a climax four weeks afterward. From blackish-brown the iris had become a bright gray-blue, in pronounced contrast to the iris of the other eye which, in spite of the injection of thorium X into the vitreous, had preserved its original brownish-black color. The right eye did not give evidence of irritation throughout the period of observation;[80] the refracting mediums remained clear and the fundus normal. In the second animal the decoloration of the iris occurred later, increased slowly, and the change in color was not so pronounced. Such less marked effect was attributed to the fact that the second rabbit had received, in the anterior chamber, a quantity of thorium X with only half the radiant energy contained in the solution injected into the anterior chamber of the first animal.

Microscopically, the chromatophores had almost completely disappeared from the iris of the injected eye of the first rabbit; only scattered residues in the form of shapeless clumps of pigment, some of which still had short and blunt processes, remained. There were diffuse fibrosis of the stroma, the nuclei of which were either absent or greatly altered; marked vacuolar degeneration or complete destruction of the vascular endothelium and degeneration of the walls of the blood vessels, but no thrombi or hemorrhages; slight swelling and vacuo-

[79] The quantity of solution injected into the anterior chamber was radioactively equivalent to 0.0045 and 0.0025 mg., respectively, of radium bromide, and the quantity injected into the vitreous equivalent to 0.009 mg. of radium bromide.

[80] Thirty-five days.

lization of the posterior pigment epithelium, and slight atrophy of the sphincter of the iris. The ciliary body was normal, except for moderate hyperemia of the ciliary processes. The lens, vitreous, choroid, and retina, as well as the lids and conjunctiva, were normal. The pathologic changes in the iris of the second rabbit were the same as in the first animal, although less pronounced. The lens, vitreous, and choroid of this rabbit also were normal. The corneal endothelium of the injected eye of the first rabbit showed deficient staining of the nuclei, and swelling and vacuolization of the protoplasm. In the second animal the corneal endothelium was entirely lacking, but Stargardt stated that, "in spite of this, the cornea was normal, both clinically and histopathologically." Klumpenzellen had not increased in the region of the sphincter and root of the iris, but there were many altered chromatophores.

One-tenth cubic centimeter of the same dilute solution of thorium X, equivalent in radioactivity to 0.009 mg. of radium bromide, was injected, under local anesthesia, into the vitreous of one eye of two rabbits[81] and of both eyes of a third rabbit. The needle of a Pravaz syringe was passed transversely through the ocular membranes in the equatorial region of the eye, the aqueous humor was removed through a small, peripheral incision in the cornea made with a lancet, and the solution of thorium X was injected slowly into the vitreous. The third rabbit also was killed one hundred eighty-eight days after the injection. Marked hyperemia of the papilla, extending about one-fourth of the diameter of the pupil, and marked dilatation of the retinal vessels became apparent within twenty-four hours. The papillary hyperemia increased during the next two days, but the retinal vessels "were now thin as threads and frequently divided." The fine medullary rays were no longer visible. The retina in the region of the papilla was clouded, and around the periphery, on the temporal side, were six small hemorrhages. Six days after the injection the upper half of the papilla was still quite hyperemic, the lower half clouded and yellowish-red, and its vessels blurred. Below the papilla, on the nasal side, were three small but fresh hemorrhages. The retinal vessels were now mere threads. The medullary rays were erased and showed numerous, grayish-white flecks. Eleven days after the injection, the papilla had recovered its normal color, but was still bleached. The hemorrhages had almost disappeared. "The medullary rays now consisted only of a white, fleck-like mass, without any striation." The fundus resembled the "salt and pepper fundus" of hereditary syphilis. Occasional cloudy patches were visible in the retina, and on the nasal side there was a large cloudy patch five to seven times the diameter of the pupil; in, or in front of, this patch a large number of white, ball-like structures were perceptible.

Seventeen days after the injection the anterior portion of the vitreous showed, especially on the nasal side, deep black, granular, cloudy areas which resembled fine coal dust and which replaced the previous pepper-and-salt aspect of the fundus. The choroidal vessels around the periphery appeared against a dirty, yellowish-gray background and in front of them lay round, deep, black clumps of pigment from one-fourth to three-fourths the diameter of the pupil. The papilla was almost white, and the clumps of dark pigment near it were often surrounded by a dirty gray halo. Only delicate remnants of the retinal vessels were visible, and the medullary wings were lacking from the peripheral third. Thirty-five days after the injection of thorium X, there were still no signs of irritation in the eye. The dark-brown iris was unchanged and the lens clear. The vitreous also was almost entirely clear, except for a few delicate, gray, cloudy areas. The black, granular areas resembling coal dust had disappeared. The papilla was snow-white, and only a few vessels were visible vertically. One medullary wing had almost disappeared; the other, previously loosened, was now wholly absent. The fundus had a lead gray color. The vessels of the choroid, greatly diminished in number, appeared as narrow, yellowish stripes covered, or interspersed, with grayish-black clumps of pigment. The earlier detachment of the retina was replaced by a

[81] The same two animals in which thorium X had previously been injected into the anterior chamber.

larger, yellowish-red, choroidal focus, in which a few vessels were still visible. Clinical evidence of ocular irritation was not found at any time. In one of the four eyes into the vitreous of which thorium X had been injected the atrophy of the papilla was accompanied by large, dirty, yellowish-red foci in the choroid. From the sixtieth day on, changes appeared in the lens. These began in the posterior layers, extended slowly to the equatorial region, and led, three or four months later, to complete opacity of the lens. In the rabbit which had received the small dose of thorium X, perceptible haziness of the lens did not appear until five months after the injection, and one month later it was still limited to the posterior layers.

The microscopic data corresponded to the clinical manifestations. The vitreous showed general liquefaction and scattered lymphocytic and phagocytic infiltration, but the nature of the black, granular, cloudy areas was not discovered. In the retina were almost complete disappearance of its nervous elements, absence of rods and cones, only remnants of the granular layers, extensive necrosis of the retinal vessels, the endothelium of which was either obliterated or exhibited marked vacuolar degeneration, and absence of thrombi and hemorrhages. The retina was represented by a delicate membrane made up of supporting tissue, occasional rests of both body layers, Abraum cells, occasional eroded vessels, and migrated pigment cells. In all cases the papilla was markedly atrophic; only scattered remnants of medullated fibers were present; the tissue contained many large, granular cells, and the vessels were altered as greatly as those of the retina. The degree of optic atrophy varied with the period between injection and death and with the dose of thorium X injected. In the choroid the most salient changes were the disappearance of stroma pigment cells, the marked shrivelling of the remaining cells which formed shapeless clumps of pigment and lay in heaps, disappearance of the pigment epithelium and clumping of the remaining cells, and marked degeneration of the blood vessels. The ciliary body was almost unaffected; only scattered swelling of the pigment epithelial cells and small vesicles was perceptible. The vessels generally were normal, and only slight changes in the endothelium were occasionally found. In the iris there was always some disintegration of chromatophores, especially in the anterior layers. The cornea was always normal. Constant changes were found in the lens of all four eyes, but in one lens these changes were slight, involved only the posterior pole, and consisted in marked swelling or complete disintegration of the fibers, numerous "vesicle-cells" and Morgagni spheres, edema, and shrivelling of some of the nuclei in the equatorial zone. The lenticular changes in the two animals killed one hundred eighty-eight days after injection were much greater and affected the entire structure, which was completely opaque. The disintegration was greatest in the equatorial region and at the posterior pole.

Stargardt interpreted these changes in the lens, not as a result of severe injury to the internal membranes of the eye by the thorium X, but as direct injury to the lens from the action of the unfiltered rays. As corroboratory evidence he adduced the fact that the anterior segment of the eyeball of his animals never gave the slightest sign of inflammatory reaction. Evidence of the action of thorium X around the point of injection was not found in any case, and Stargardt believed that the changes at this point noted by Abelsdorff were due to a difference in technique. Stargardt concluded that, although the lens of adult animals possesses a high degree of resistance to roentgen and radium rays, such resistance is not absolute, especially when the radioactive substance is injected into the eye. He contended that the therapeutic injection of thorium X into the eye is too dangerous to be warranted.

Meisner (1924) introduced into the vitreous of one eye, in each of twelve rabbits,[82] tiny, sterilized tubes[83] about 1 cm. long, 0.5 mm. thick, and containing from about 0.6 to 0.15 millicuries of radium emanation. Preliminary tests with empty tubes left within the

[82] Age not given.
[83] The character of these tubes and the filtration value of their wall were not stated.

tissues of the eye as long as two months did not lead to cataract formation or give rise to inflammatory reaction. Similar tubes, not containing radium, were introduced into the vitreous of the other eye of each animal to provide control conditions. The dose of radium emanation and the resulting ocular changes were not described separately for each animal. Meisner stated that the introduction of 0.68 millicuries of emanation into the vitreous was followed, after eight days, by slight fading of the papilla, apparently due to fine clouding of the vitreous. Slight blurring of the aqueous humor and fine precipitation on the anterior capsule of the lens were visible twelve days after introduction of the radium emanation. The lens also showed the silken luster of a definite nuclear layer. Maximal dilatation of the pupils to atropine did not occur. The vitreous was diffusely cloudy; the cloudiness was especially marked anteriorly, and after sixteen days a husk-like opacity of the posterior capsule was noted. The lens became totally opaque after one month, and this was associated with complete degeneration of the retina, irregularity of the pigment epithelium, and extensive atrophy of the medullary substance after two and a half months. The choroid apparently was intact. The ocular changes in one animal, after the introduction of 0.48 millicuries of radium emanation into the vitreous, were described as consisting, after thirteen days, in narrowing of the vessels and medullary wings, which became small and lumpy and then appeared as fine, bright yellow and black points. The posterior pole of the lens also became cloudy. Ten days after the introduction of 0.34 millicuries of emanation, opacification of the posterior pole of the lens, increasing but slightly during the next two months, was noted. The vitreous was only slightly cloudy, and the rods were distinctly visible. Except for narrowing of the vessels and considerable atrophy of the ganglion cell layer, the fundus was normal. The optic nerve was unaffected. Meisner concluded that irradiation may cause cataract-like changes in the lens of adult animals, as well as degeneration of the ganglion cells of the retina and of the medullary sheaths of the optic nerve.

Takahashi (1924) investigated the action of radium on tuberculosis induced in six rabbits by introducing into the anterior chamber pieces of tuberculous material or carefully diluted suspensions of *Mycobacterium tuberculosis*. After a variable period of incubation tuberculous lesions of the iris developed in every instance. A piece of tuberculous tissue was injected into the anterior chamber of the left eye of an albino rabbit weighing 1125 gm. A short period of inflammatory reaction ensued, but this subsided rapidly. Four weeks later increase in conjunctival secretion, slight ciliary injection, moderate redness and swelling, and yellowish-gray, miliary nodules developed in the iris. A circumscribed, proliferative inflammation around the point of injection at the border of the cornea occurred five days later. The tubercles in the iris continued to increase in number and in size, and the oval pupil, with marked posterior synechia, became closed by masses of exudate. Seven weeks after inoculation the eye was exposed to the action of 49.46 mg. of radium bromide enclosed in a glass tube covered with platinum 0.5 mm. thick for from fourteen to seventeen hours on each of four successive days.[84] Regression of the granulation tissue at the margin of the cornea, decrease in redness and in the size and number of the miliary tubercles in the iris became perceptible after one week, and this was accompanied by loss of the cilia and hair from the eyelids. The condition of the cornea, conjunctiva, and iris improved, and the miliary tubercles diminished steadily. The hair of the lids began to grow again, and eighty-eight days after the injection the eye was free from any evidence of tuberculosis or other abnormality.

The second rabbit, weighing 2000 gm., received a dilute suspension of *Mycobacterium tuberculosis* (human type) in the anterior chamber of the left eye. This was followed by an inflammatory reaction which subsided completely in ten days. Ciliary injection and exudate at the margins of the pupil appeared four weeks after the injection, and yellowish miliary

[84] Total duration of exposure, fifty-five hours (discrepancy not accounted for).

nodules on the reddened and swollen iris appeared five weeks after the injection. The tubercles gradually increased in number and size; the inflammation of the iris became more marked; two miliary nodules developed around the point of injection in the cornea, with mucous conjunctivitis, and protrusion of the eyeball was evident eight weeks after injection. Two weeks later yellowish nodules appeared on the posterior surface of the cornea and on the ocular conjunctiva, and the tuberculous iritis had progressed further. Ten weeks after inoculation, the eye was irradiated[85] for from one hour and a half to eight hours eight times in two weeks (total duration of exposure, fifty-two hours). Within one week the exophthalmos had disappeared almost completely; the tuberculous iritis and all the other inflammatory manifestations, except some redness and swelling of the iris, had disappeared two months later, and did not recur subsequently.

The third rabbit, an albino weighing 2270 gm., received in the anterior chamber, through an incision in the cornea, a small piece of tuberculous iris from another rabbit. The immediate inflammatory reaction subsided in two weeks, redness and swelling of the iris appeared in three weeks, and miliary nodules around the margin of an irregularly round pupil, with moderate ciliary injection, became evident four weeks after the inoculation. Decrease in the depth of the anterior chamber, haziness of the cornea, and swelling and partial adhesion of the iris by a grayish-white exudate developed during the fifth week; miliary tubercles appeared ten weeks after inoculation and increased steadily in number and size. Seven weeks after inoculation the eye was irradiated.[86] from fourteen to seventeen hours on each of four successive days (total duration of exposure, sixty-five hours). During the ensuing week the haziness of the cornea diminished, the miliary tubercles in the iris began to recede, and epilation around the site of irradiation occurred. Seventeen days after the last session of irradiation the conjunctiva was still slightly red, but the haziness of the cornea and the tubercles and surrounding inflammation of the iris had disappeared and did not recur. Shortly afterward hair, which had disappeared from the irradiated portion of the eyelids, began to grow again.

The fourth rabbit, an albino weighing 2240 gm., received a piece of tuberculous tissue in the anterior chamber of the left eye; this was absorbed in two weeks, and the eyeball showed almost no sign of irritation. Twenty-two days later ciliary injection, slight reddening and swelling of the iris, and posterior synechia at the edges of the pupil became manifest. Five days later conjunctivitis and miliary nodules in the iris had developed; this was soon accompanied by haziness of the cornea, and the miliary nodules in the markedly swollen iris increased in number and size during the next twenty-three days. Eight weeks after inoculation the eye was irradiated[86] from three to twenty-four hours on each of four successive days (total duration of exposure, seventy-eight hours). The secretion of the conjunctiva, the cloudiness of the cornea, and the iritis all decreased steadily during the five ensuing weeks, but the posterior synechia around the oval pupil persisted, the miliary nodules in the iris continued to increase, and much of the hair fell from the upper eyelid. Seven weeks after irradiation the cornea was almost normally clear, the iris was no longer hyperemic, and all but one of the nodules on the lower edge of the pupil had vanished; the inflammatory changes in the iris had receded almost completely, but there was some secondary atrophy. The tuberculous lesions did not recur.

The sixth rabbit, an albino weighing 1132 gm., received in the subconjunctiva, near the upper, outer border of the cornea, a small piece of tuberculous iris, which was absorbed during the next seventeen days, when the eye was free from irritation. Conjunctivitis appeared twenty-three days after the inoculation. The cornea and iris remained normal. The circumscribed conjunctivitis increased and, after four weeks, formed an elevation about 1 cm. in diameter and covered with miliary nodules. The tuberculous process showed

[85] The conditions of irradiation and the quantity of radium were the same as for the first animal.
[86] The quantity of radium and the conditions of irradiation were the same as for the previous animal.

a tendency to extend during the next two weeks. Six weeks after inoculation the eye was irradiated[87] from fifteen to seventeen hours on three occasions, with an interval of nine days between the first and second sessions and one day between the second and third (total duration of exposure, forty-seven hours). The inflammatory manifestations subsided steadily during the next three weeks and, except for a blackish discoloration at the site of the lesion, had disappeared completely twenty-four days after irradiation, and did not recur.

The inoculated and irradiated eye of each of these six animals was submitted to microscopic examination.[88] The only indications of active inflammation consisted in scanty proliferation of connective tissue; occasional foci of lymphocytic infiltration, especially in the iris and at the border of the cornea; small, newly formed blood vessels in the iris, but "not a trace of tuberculosis." Takahashi concluded that doses of radium such as those employed by him cause tuberculous lesions of the eye and the associated inflammatory manifestations to disappear; that the reason of Flemming's failure to obtain similar results probably was because he used smaller doses, and that epilation of the portion of the lids where the radium had been applied was the only injurious secondary effect.

To determine if the beta and gamma rays of radium have a direct action on *Mycobacterium tuberculosis*, Takahashi exposed such bacilli (human type) in bouillon culture to the action of about 50 mg. of radium, at a distance of about 3 mm., from forty-five to three hundred hours. A suitable dose of the suspension thus irradiated was injected into the peritoneal cavity of guinea pigs, and "after a certain length of time" the animals were killed. Pathologic examination showed that the bacilli were still infectious after two hundred hours of irradiation. Therefore, the results of irradiation in tuberculous disease of the eye could not be attributed to bactericidal action.

Assuming that the protein content of the aqueous humor is closely related to the healing process in diseases of the eye, Takahashi first established that a result of irradiating the eye of normal rabbits for two or three hours is a transient, but distinct, increase in the protein content of the aqueous humor. A uniform increase, attaining its maximum ten hours after exposure, was noted in eyes irradiated for five hours. After irradiation for fifteen hours the increase in protein content of the aqueous humor was still evident three weeks later. On the assumption that the therapeutic value of paracentesis of the cornea, in conditions such as ulcus serpens, rests on the richness of the aqueous humor in protein and protective substances formed after the puncture, and that the value of subconjunctival injection of physiologic solution of sodium chloride also rests on an increase in protein content, Takahashi thought the action of radium on tuberculous affections of the eye may be similar, with the difference that in tuberculous lesions this effect is prolonged.

[87] The conditions of irradiation and the quantity of radium were the same as for the first animal.
[88] The method of preparation and staining, and a detailed description of the findings were not given.

To be continued.